Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 267 APRIL, 1959 No. 4

A CLASS OF OPTIMUM CONTROL SYSTEMS

BY

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ABSTRACT

A class of optimum control systems is defined and investigated with special emphasis on time-domain concepts. This class of optimum systems is particularly suitable for feedback-control applications where adaptability to changing conditions is desired.

Computational and physical simplifications are studied when mathematical restrictions are imposed on the error criterion and the dynamic process. For a quadratic error criterion and a linear dynamic process, the optimum configuration of the control system is defined and discussed in terms of available measurements. For the case where, in addition, the control variable is not restricted in range, topics of separability and linearity are presented.

DEFINITION

The modern development of system design methods has been influenced strongly by the optimization theory of Wiener (1).[2] Lee (2) applied Wiener's theory to design problems in the communication area, and more recently Newton (3) enhanced the application of Wiener's work to feedback-control design problems by the addition of mathematical constraints relating to bandwidth and saturation. These mathematical constraints represent design considerations which are dictated by the intent and the physical realization of the control system.

The basic theory of Wiener and its applications are classified here in broad terms as filter theory because the methods only result in a specification of the system weighting function without regard to the configuration of the system components. As opposed to filter theory, control theory must, in addition, specify the optimum configuration of the control system. The importance of system configuration arises

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

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from the frequent occurrences of additive load disturbances, such as initial conditions, because configuration determines the sensitivity of the system response to these disturbances.

For this work, the dynamic process is defined as being characterized by the differential relationship[3]

$$q^{(U)}(t) = F[q^{(U-1)}(t), \cdots, q^{(1)}(t), q(t); m^{(V)}(t), \cdots, m^{(1)}(t), m(t)], \quad (1)$$

where $V \leq U$ and where $m(t)$ is the control (independent) variable[4] and $q(t)$ is the response (dependent) variable. The notation $x^{(y)}(\sigma)$ implies the y^{th} derivative of $x(\sigma)$ with respect to σ.

Subject to the dynamic process given in Eq. 1, the class of design problems of interest here is that class in which the error criterion

$$e = \int_t^{t+\tau} \{\lambda(\sigma) f_q[Q(\sigma) - q(\sigma)] + f_m[M(\sigma) - m(\sigma)]\} d\sigma \quad (2)$$

is meaningful in regard to engineering and/or economic considerations. In Eq. 2, response errors are weighted in reference to the function $Q(\sigma)$ which is defined here as the best available estimate[5] of the desired response variable; similarly the function $M(\sigma)$ is defined as the best available estimate of the desired control variable. The functions $f_q(x)$ and $f_m(x)$ determine the method of weighting errors in the respective variables.[6] The function $\lambda(\sigma)$ is an arbitrary weighting factor which specifies the relative weighting between errors in the process control variable and errors in the process response variable. Finally, the variable t is reserved for present time, and hence in Eq. 2 the dummy variable σ ranges over an interval τ of future time.

The explicit design of the class of systems being studied here is specified by the condition which minimizes the error function given in Eq. 2 at any time t subject to a magnitude restriction on the range of the control variable. Here the tacit assumption is made that the functions f_q and f_m are strictly concave and that the weighting function $\lambda(\sigma)$ satisfies $\lambda(\sigma) \geq 0$, thereby insuring a unique minimum condition. The class of optimum control systems defined by this minimum condition is called adaptive since minimum error is maintained at every in-

[3] For definition of terms, see Glossary at the end of this paper.

[4] The reader should note that the control variable $m(t)$ is not required to be identically the input variable to the so-called fixed elements in the system if the fixed elements are linear. For nonlinear fixed elements which can be described by a relationship similar to Eq. 1, the tacit assumption is made that the control variable $m(t)$ is synonymous with the input to the fixed elements in order to insure extensions of this work to these nonlinear cases without additional concepts.

[5] Estimations or extrapolations can be based on any form of mathematical or subjective analysis of the variables involved, whether deterministic or nondeterministic, although response errors due to estimation errors cannot be evaluated without a mathematical description of the signals. For example, adaptive controls can be combined with optimum mean-square filters such as Wiener-Lee (2) and Zadeh-Ragazzini (4).

stant t, and the possibility exists of altering the control system subject to changes in the characteristics of the functions $Q(\sigma)$ and $M(\sigma)$.

CONDITION FOR OPTIMUM

The solution of the minimization problem required to specify the class of systems defined here generally cannot be determined by calculus of variations (5) without additional trial-and-error techniques. Consequently, the condition defining the optimum system is established here using the functional-equation methods of Bellman (6). This alternative approach not only makes possible a sequential computational solution to the minimization problem for the general class but also leads to the derivation of important properties of a large subclass of problems.

If the functions $Q(\sigma)$ and $M(\sigma)$ are assumed given, a property of the minimum error as given by the minimization of Eq. 2 is that the minimum error is only dependent upon the state of the dynamic process at time t. Here the state variable $z(t)$ is defined such that the set of variables $z^{(U-1)}(t), \cdots, z^{(1)}(t), z(t)$ uniquely determines the state of the dynamic process at time t, and the functional given in Eq. 1 is assumed to be such that the variables in the dynamic process can be written as

$$q(t) = F_q[z^{(V)}(t), \cdots, z^{(1)}(t), z(t)] \tag{3}$$

and

$$m(t) = F_m[z^{(U)}(t), \cdots, z^{(1)}(t), z(t)]. \tag{4}$$

Now the functional dependence of the minimum error mathematically can be expressed from Eq. 2 as

$$E[z^{(U-1)}(\mu), \cdots, z^{(1)}(\mu), z(\mu); \mu] = \min_{\substack{\mathfrak{L}[z^{(U)}(\sigma)] \\ \mu \le \sigma \le t+\tau}} \left[\int_{\mu}^{t+\tau} \{\lambda(\sigma) f_q[Q(\sigma) - q(\sigma)] + f_m[M(\sigma) - m(\sigma)]\} d\sigma \right], \tag{5}$$

where $\mathfrak{L}[z^{(U)}(\sigma)]$ is an abbreviation for $L^-(\sigma) \le z^{(U)}(\sigma) \le L^+(\sigma)$ and the function $L^-(\sigma)$ and $L^+(\sigma)$ are assumed given and where the dummy variable μ is in the interval $t \le \mu \le t + \tau$.

In order to specify the minimum error function given in Eq. 5, a discrete recurrence relationship is sought. To this end an arbitrarily small increment ϵ of the dummy variable σ is introduced such that Eq. 5 becomes

$$E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] = \min_{\substack{\mathfrak{L}[z^{(U)}(\sigma)] \\ \mu \le \sigma \le t+\tau}} \left[\epsilon \{\lambda(\mu) f_q[Q(\mu) - q(\mu)] + f_m[M(\mu) - m(\mu)]\} + \int_{\mu+\epsilon}^{t+\tau} \{\lambda(\sigma) f_q[Q(\sigma) - q(\sigma)] + f_m[M(\sigma) - m(\sigma)]\} d\sigma \right]. \tag{6}$$

By a simple extension of the definition for the minimum error function which is given in Eq. 5, the minimum error function satisfies

$$E[z^{(U-1)}(\mu+\epsilon), \cdots, z(\mu+\epsilon); \mu+\epsilon] \leq \int_{\mu+\epsilon}^{t+\tau} \{\lambda(\sigma) f_q[Q(\sigma) - q(\sigma)] + f_m[M(\sigma) - m(\sigma)]\} d\sigma \quad (7)$$

for all possible states of the process at time $\mu + \epsilon$. The integral appearing in Eq. 6 now can be replaced by the minimum error function $E[z^{(U-1)}(\mu+\epsilon), \cdots, z(\mu+\epsilon); \mu+\epsilon]$ as a result of the condition given in Eq. 7 which insures that the resulting minimum is always less than or equal to the minimum given in Eq. 6[7]; hence

$$E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] = \min_{\mathfrak{L}[z^{(U)}(\mu)]} \Big[\epsilon\{\lambda(\mu) f_q[Q(\mu) - q(\mu)] + f_m[M(\mu) - m(\mu)]\} + E[z^{(U-1)}(\mu+\epsilon), \cdots, z(\mu+\epsilon); \mu+\epsilon] \Big], \quad (8)$$

where $E[z^{(U-1)}(t+\tau), \cdots, z(t+\tau); t+\tau] = 0$ as can be seen from Eq. 5. The recurrence equation given in Eq. 8[8] expresses the discrete condition for minimum error subject only to the structural requirements for uniqueness and to the functional form required of the dynamic process as expressed in Eqs. 3 and 4. Also the recurrence relationship between successive minimum error functions is subject to the computational advantages and disadvantages normally associated with dynamic programming (6).

In order to establish analytical properties of a subclass of adaptive control systems, the continuous form of the condition for minimum error is derived here. Since the increment ϵ is arbitrarily small, the minimum error function can be approximated by the truncated Taylor series

$$E[z^{(U-1)}(\mu+\epsilon), \cdots, z(\mu+\epsilon); \mu+\epsilon] = E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] + \epsilon E_\mu[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] + \epsilon \sum_{u=0}^{U-1} z^{(u+1)}(\mu) E_{(u)}[z^{(U-1)}(\mu), \cdots, z(\mu); \mu], \quad (9)$$

where a partial derivative notation

$$E_\mu[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] = \frac{\partial E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu]}{\partial \mu}$$

[6] For $f_q(x) = f_m(x) = x^2$, the error criterion generally is called quadratic.
[7] This is equivalent to Bellman's Principle of Optimality.

and

$$E_{(u)}[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] = \frac{\partial E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu]}{\partial z^{(u)}(\mu)}$$

has been introduced. Now substitution of Eq. 9 into Eq. 8 gives

$$E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu]$$

$$= \min_{\mathcal{L}[z^{(U)}(\mu)]} \Bigg[\epsilon\{\lambda(\mu) f_q[Q(\mu) - q(\mu)] + f_m[M(\mu) - m(\mu)]\} + E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] + \epsilon E_\mu[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] + \epsilon \sum_{u=0}^{U-1} z^{(u+1)}(\mu) E_{(u)}[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] \Bigg]. \quad (10)$$

Because the minimum error function $E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu]$ appears on both sides of the equality in Eq. 10, it does not enter into the minimization operation and hence is eliminated. Then the increment ϵ can be cancelled thereby giving the continuous form of the minimum error condition

$$\min_{\mathcal{L}[z^{(U)}(\mu)]} \Bigg[\lambda(\mu) f_q[Q(\mu) - q(\mu)] + f_m[M(\mu) - m(\mu)] + E_\mu[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] + \sum_{u=0}^{U-1} z^{(u+1)}(\mu) E_{(u)}[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] \Bigg] = 0. \quad (11)$$

SOLUTION OF OPTIMUM CONDITION FOR A SUBCLASS

In general, the computational procedures required for the solution of the minimum error condition are not suitable for the time scale of many feedback-control applications. Therefore a subclass of systems is discussed here which possesses a simplified form. This subclass is specified by the assumptions of a linear dynamic process, given as[9]

$$q(t) = \sum_{u=0}^{U-1} b_u(t) z^{(u)}(t) \quad (12)$$

and

$$m(t) = \sum_{u=0}^{U} a_u(t) z^{(u)}(t), \quad (13)$$

where $a_U(t) = 1$, and a quadratic error criterion. With these assumptions, Eq. 11 becomes

[8] Note that the minimization is in respect to $z^{(U)}(\mu)$ only, since $E[z^{(U-1)}(\mu + \epsilon), \cdots, z(\mu + \epsilon); \mu + \epsilon]$ specifies $z^{(U)}(\sigma)$ on the interval $\mu + \epsilon < \sigma \leq t + \tau$.

[9] The case with $b_U \neq 0$ involves no additional concepts but considerably more algebra.

$$\min_{\mathcal{L}[z^{(U)}]} \left[\lambda [Q - \sum_{u=0}^{U-1} b_u z^{(u)}]^2 + [M - \sum_{u=0}^{U} a_u z^{(u)}]^2 + E_\mu + \sum_{u=0}^{U-1} z^{(u+1)} E_{(u)} \right] = 0, \quad (14)$$

where functional notation has been dropped for convenience.

The minimizing function, $z^{(U)}(\mu)$, is established by first assuming that $z^{(U)}$ satisfies the equation $L^- < z^{(U)} < L^+$ and then taking the first partial of Eq. 14 with respect to $z^{(U)}$. If the resulting $z^{(U)}$ does not satisfy $L^- < z^{(U)} < L^+$, the minimizing $z^{(U)}$ is equal to the corresponding limit. Hence the minimizing function is

$$z^{(U)} = \begin{cases} L^+, & L^+ \leq z_L{}^{(U)} \\ z_L{}^{(U)}, & L^- < z_L{}^{(U)} < L^+ \\ L^-, & z_L{}^{(U)} \leq L^- \end{cases} \quad (15)$$

where

$$z_L{}^{(U)} = M - \sum_{u=0}^{U-1} a_u z^{(u)} - \tfrac{1}{2} E_{(U-1)}. \quad (16)$$

The condition on the minimum error function now becomes

$$\lambda [Q - \sum_{u=0}^{U-1} b_u z^{(u)}]^2 + [M - \sum_{u=0}^{U} a_u z^{(u)}]^2 + E_\mu + \sum_{u=0}^{U-1} z^{(u+1)} E_{(u)} = 0, \quad (17)$$

where $z^{(U)}$ is given by Eq. 16.

The solution for the minimum error function, as given by the partial differential equation in Eq. 17, is accomplished by assuming a series solution. The minimizing error function is taken to be[10]

$$E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu] = K(\mu) + \sum_{u=0}^{U-1} K_u(\mu) z^{(u)}(\mu) + \sum_{u=0}^{U-1} \sum_{v=0}^{U-1} K_{uv}(\mu) z^{(u)} z^{(v)}, \quad (18)$$

where $K_{uv} = K_{vu}$ and $K(t + \tau) = K_u(t + \tau) = K_{uv}(t + \tau) = 0$. The needed partial derivatives are written in abbreviated notation as

$$E_\mu = K^{(1)} + \sum_{u=0}^{U-1} K_u{}^{(1)} z^{(u)} + \sum_{u=0}^{U-1} \sum_{v=0}^{U-1} K_{uv}{}^{(1)} z^{(u)} z^{(v)} \quad (19)$$

and

$$E_{(u)} = K_u + 2 \sum_{v=0}^{U-1} K_{uv} z^{(v)}. \quad (20)$$

[10] A more general series can be chosen but all additional coefficients can be shown to be zero.

Upon the proper substitutions, Eq. 17 can be written in a form with the state variables factored as

$$[K^{(1)}(\mu) - \mathfrak{F}] + \sum_{u=0}^{U-1} [K_u{}^{(1)}(\mu) - \mathfrak{F}_u]z^u + \sum_{u=0}^{U-1} \sum_{v=0}^{u} [K_{uv}{}^{(1)}(\mu) - \mathfrak{F}_{uv}]z^{(u)}z^{(v)} = 0, \quad (21)$$

where the $\mathfrak{F}$'s represent combinations of the various K-parameters. In order to satisfy the minimum error condition for all combinations of the state variables, $1 + 2U + U!/2!(U-2)!$ conditions are imposed by setting each bracket in Eq. 21 equal to zero. Therefore, an equal number of ordinary differential equations results. For the case where $z^{(U)} = z_L{}^{(U)}$, the parameters in the minimum error function are given as

$$K^{(1)} = -\lambda Q^2 + \tfrac{1}{4}K_{U-1}{}^2 - MK_{U-1}, \quad (22)$$

$$K_u{}^{(1)} = 2\lambda Q b_u + K_{U-1}K_{U-1,u} - K_{u-1} - 2MK_{U-1,u} + K_{U-1}a_u, \quad (23)$$

and

$$K_{uv}{}^{(1)} = -\lambda b_u b_v + K_{U-1,u}K_{U-1,v} - K_{u-1,v} + a_u K_{U-1,v} - K_{v-1,u} + a_v K_{U-1,u}. \quad (24)$$

For the case where $z^{(U)} = L$ where L is either L^+ or L^-, the parameters are

$$K^{(1)} = -\lambda Q^2 - (M-L)^2 - LK_{U-1}, \quad (25)$$

$$K_u{}^{(1)} = 2\lambda Q b_u + 2(M-L)a_u - K_{u-1} - 2LK_{U-1,u}, \quad (26)$$

and

$$K_{uv}{}^{(1)} = -\lambda b_u b_v - a_u a_v - K_{u-1,v} - K_{v-1,u}. \quad (27)$$

Here $v \leq u$, $u = 0, \cdots, U-1$, and the parameters K_{-1} and $K_{-1,u}$ are defined as zero.

The numerical solution of this set of equations can be found simply with the aid of an analogue computer and use of Eqs. 15 and 16.

PROPERTIES OF THE SUBCLASS

Before discussing the optimum control system, some properties of the minimum error function are presented, which readily can be associated with control system characteristics. In particular, as a result of the positiveness of the quadratic form of the error criterion, the minimum error function is positive for all possible states of the dynamic

process and all possible forms of the functions Q and M. This positiveness property implies that the minimum error function parameters satisfy the following for all μ, u, and v not equal to u; $K(\mu) \geq 0$, $K_{uu} \geq 0$, $|K_u| \leq 2[KK_{uu}]^{1/2}$, and $|K_{uv}| \leq [K_{uu}K_{vv}]^{1/2}$.

The optimum control law is specified by Eq. 16 with the substitution of Eqs. 13 and 20, thereby giving

$$m(t) = [z^{(U)}(t) - z_L{}^{(U)}(t)] + [M(t) - \tfrac{1}{2}K_{U-1}(t)] - [\sum_{u=0}^{U-1} K_{U-1,u}(t)z^{(u)}(t)]. \tag{28}$$

The first bracket in Eq. 28 is called the switching portion of the control system where $z^{(U)}(t)$ is given by Eq. 15. The second bracket in Eq. 28 is called the director portion, and the third bracket is termed the feedback portion. The importance of this optimum control law is that Eq. 28 gives the control system configuration that is optimum for all present ($\mu = t$) and future ($t < \mu \leq t + \tau$) states of the dynamic process. In other words, the control system is optimum for all measurable initial conditions and all predictable additive load disturbances. However, this topic is discussed further in terms of a more specialized subclass, which, in addition to the present restrictions, is defined by an infinite range of $z^{(U)}(\mu)$.

For the case where the limits of $z^{(U)}(\mu)$ are $L^+(\mu) < \infty$ and $-\infty < L^-(\mu)$, Eqs. 22, 23 and 24 specify completely the K-parameters, and the optimum control law becomes

$$m(t) = [M(t) - \tfrac{1}{2}K_{U-1}(t)] - [\sum_{u=0}^{U-1} K_{U-1,u}(t)z^{(u)}(t)]. \tag{29}$$

In this more specialized class, the optimum control system parameters are invariant with respect to all initial conditions and future states of the process. However, the optimum system response is predicated upon the measurement of the present values of the process state variable which appear in the optimum configuration expressed in Eq. 29. Of course the possibility of relocating terms in the feedback portion of the control system exists because the dynamic process is linear, and deviations from the optimum configuration are desirable when one or more state variables cannot be measured directly. The relocation of feedback terms can be accomplished with appropriate compensation so as to preserve the optimum system response with respect to the desired response and control variables $Q(t)$ and $M(t)$ if the corresponding initial conditions are zero. On the other hand, if an initial condition which cannot be measured is not zero, then this state variable can be determined by a linear combination of $2U$ measurements on the process response and control variables and is expressed as

$$g^{(u)}(t) = \sum_{v=0}^{U-1} Q_{uv}(t)q^{(v)}(t) + \sum_{v=0}^{U-1} M_{uv}(t)m^{(v)}(t). \tag{30}$$

The conversion coefficients $Q_{uv}(t)$ and $M_{uv}(t)$ are formed from the coefficients of the dynamic process which appear in Eqs. 12 and 13 (7).

Because Eqs. 22, 23 and 24 are sufficient to determine the K-parameters for the case of an infinite range control variable, additional important properties of the optimum control system result. In particular, Eq. 24 specifies completely the feedback portion of the control system, and hence this portion is not dependent upon the desired response and control functions $Q(\mu)$ and $M(\mu)$. Therefore, the invariant feedback portion is termed nonadaptive, and the optimum control system is termed separable (into adaptive and nonadaptive portions). A direct consequence of this separability is that the director portion, as given by Eq. 23, is linear with respect to the functions $Q(\mu)$ and $M(\mu)$ because now the parameters K_{uv} are independently varying multipliers.

LINEAR ESTIMATION WITH SEPARABLE CLASS

The design of adaptive control systems requires an estimation of the desired response and control variables everywhere on the interval of future time where response errors are weighted. Discussed here is the class of functions that can be estimated with a linear physical operation

$$Q(\mu) = \int_{-\infty}^{t} h(\mu, \alpha)v(\alpha)d\alpha \tag{31}$$

as expressed for the desired response variable where $\mu \geq t$. The function $v(\alpha)$ is assumed to contain an additive component of $i(\alpha)$ which is defined to be the exact value of the desired response variable. The function $h(\mu, \alpha)$ is the impulse response of the N^{th} order linear operation and generally has the form

$$h(\mu, \alpha) = \sum_{n=1}^{N} H_n(\mu)h_n(\alpha), \tag{32}$$

where $H_n(\sigma)$ is a parameter and $h_n(\alpha)$ is a linearly independent solution of the homogeneous ordinary differential equation (8). Therefore the desired response variable can be written as

$$Q(\mu) = \sum_{n=1}^{N} Q_n(t) \frac{H_n(\mu)}{H_n(t)}, \tag{33}$$

where the response of a first order differential equation is defined as

$$Q_n(t) = \int_{-\infty}^{t} H_n(t)h_n(\alpha)v(\alpha)d\alpha. \tag{34}$$

Linear estimation as expressed in Eq. 31 is typical of extrapolation with a truncated Taylor series and of Wiener statistical prediction as discussed subsequently.

In the separable adaptive control system, the director equations are linear, and an impulse response can be defined so that the director output can be expressed in terms of the superposition integral

$$K_{U-1}(t) = \int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)Q(\mu)d\mu, \tag{35}$$

where the desired control function $M(\mu)$ is assumed zero.[11] The function $h_{dq}(\tau, \beta)$ is defined as the response $K_{U-1}(\zeta)$ and $\zeta = \tau$ due to a unit impulse at $\zeta = \beta$ where the dummy variable ζ is defined as $\zeta = t + \tau - \mu$ for use in Eqs. 22, 23 and 24. With the substitution of Eq. 33, the director output can be written as

$$K_{U-1}(t) = \sum_{n=1}^{N} Q_n(t)\,\mathfrak{K}_n(t, \tau), \tag{36}$$

where the no-energy storage again $\mathfrak{K}_n(t, \tau)$ is

$$\mathfrak{K}_n(t, \tau) = \int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)\frac{H_n(\mu)}{H_n(t)}d\mu. \tag{37}$$

Therefore with linear estimation in the separable adaptive control system, the total effect of the director portion of the control system can be expressed as N gains where each gain multiplies the output of a first order linear estimator.

If the estimator and/or the director are time invariant, Eq. 37 is simplified somewhat. For a time-invariant estimator, the impulse response can be written such that

$$h_n(\alpha) = e^{\alpha/\tau_n} \quad \text{and} \quad H_n(\mu) = f_n e^{-\mu/\tau_n}.$$

Therefore Eq. 37 becomes

$$\mathfrak{K}_n(t, \tau) = \int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)e^{-(\mu-t)/\tau_n}d\mu. \tag{38}$$

Also if the director equations are time invariant as is the case only when $\tau = \infty$ and the weighting factor $\lambda(\mu)$ is a constant, then the director equation impulse response can be written as $h_{dq}(\mu - t)$. With a change of variables $\mu - t = \gamma$, Eq. 38 now becomes

$$\mathfrak{K}_n(t, \tau) = \int_0^{\infty} h_{dq}(\gamma)e^{-\gamma/\tau_n}d\gamma. \tag{39}$$

[11] The results of this section can be generalized to the case where $M(\mu) \neq 0$ by defining an additional impulse response h_{dm}.

In this special case, the director gains are time invariant. Also the director impulse response can be written as a sum of exponentials, and hence Eq. 39 is integrated readily. Therefore in this case, the optimum control system can be derived analytically (3).

OPTIMUM MEAN-SQUARE PREDICTION IN SEPARABLE CLASS

Since estimation errors occur with functions which possess random components, an evaluation of errors in predicting these random components is presented here for the separable class of adaptive control systems. Here the errors in the response of the dynamic process due to prediction errors are weighted with a mean-square criterion.

The error in the director output due to prediction errors is defined as

$$e_{dq}(t) = \int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)[Q(\mu) - i(\mu)]d\mu. \tag{40}$$

Also a mean-square error in the director output is defined as

$$\overline{e_{dq}^2(t)} = \overline{\left\{\int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)[Q(\mu) - i(\mu)]d\mu\right\}^2}, \tag{41}$$

where the bar denotes any ensemble average which is commutative with other linear mathematical operations. Minimization of the mean-square error in the director output produces a minimum mean-square error in the response of the dynamic process because the feedback portion is independent of the desired response variable $Q(\mu)$ and also is linear with respect to the director output.[12]

The minimum mean-square error criterion is developed here by variational calculus. The assumption is made that $Q^*(\mu)$ exists which is optimum in the mean-square sense and is taken from a class of functions $\{Q(\mu)\}$. The expression which relates $Q^*(\mu)$ to the other members of the class of functions $\{Q(\mu)\}$ is

$$Q(\mu) = Q^*(\mu) + \delta\eta(\mu), \tag{42}$$

where δ is a parameter which is independent of μ and $\eta(\mu)$ is an arbitrary variation. Now the mean-square error becomes

$$\overline{e_{dq}^2(t)} = \overline{\left\{\int_t^{t+\tau} h_{dq}(\tau, t + \tau - \mu)[Q^*(\mu) + \delta\eta(\mu) - i(\mu)]d\mu\right\}^2}, \tag{43}$$

and the first two derivatives with respect to the parameter δ are

$$\frac{\partial \overline{e_{dq}^2(t)}}{\partial\delta} = 2\overline{\int_t^{t+\tau} h_{dq}(\tau, t+\tau-\mu)[Q^*(\mu)-\delta\eta(\mu)-i(\mu)]d\mu \int_t^{t+\tau} h_{dq}(\tau, t+\tau-\mu)\eta(\mu)d\mu} \tag{44}$$

[12] The subsequent development in addition demonstrates that the optimum mean-square prediction is independent of the linear director equations.

and

$$\frac{\partial \overline{e_{d_q}^2(t)}}{\partial \delta^2} = 2\left[\int_t^{t+\tau} h_{d_q}(\tau, t+\tau-\mu)\eta(\mu)d\mu\right]^2. \tag{45}$$

Since Eq. 45 is always greater than or equal to zero, a minimum mean-square error is obtained when Eq. 44 is zero as the parameter δ goes to zero, and hence

$$\int_t^{t+\tau}\int_t^{t+\tau} h_{d_q}(\tau, t+\tau-\mu)h_{d_q}(\tau, t+\tau-\alpha)[\overline{Q^*(\mu)\eta(\alpha)} - \overline{i(\mu)\eta(\alpha)}]d\mu d\alpha = 0. \tag{46}$$

In order to satisfy this condition for a minimum with an arbitrary weighting of response errors (that is for all h_{d_q}), the following equality must be satisfied:

$$\overline{Q^*(\mu)\eta(\alpha)} = \overline{i(\mu)\eta(\alpha)}. \tag{47}$$

From Eq. 42, the condition given in Eq. 47 for a minimum can be written as

$$\overline{Q^*(\mu)Q(\alpha)} - \overline{Q^*(\mu)Q^*(\alpha)} = \overline{i(\mu)Q(\alpha)} - \overline{i(\mu)Q^*(\alpha)}. \tag{48}$$

The solution of Eq. 48 is chosen to be

$$\overline{Q^*(\mu)Q(\alpha)} = \overline{i(\mu)Q(\alpha)} \tag{49}$$

which requires that

$$\overline{Q^*(\mu)Q^*(\alpha)} = \overline{i(\mu)Q^*(\alpha)}, \tag{50}$$

when $Q(\mu) = Q^*(\mu)$. Now the minimum mean-square error in the director output, denoted by $\overline{e_{d_q}^2(t)}\big|_{\min}$, can be found when $Q(\mu) = Q^*(\mu)$ and Eq. 50 are substituted into Eq. 43, thereby giving

$$\overline{e_{d_q}^2(t)}\big|_{\min} = \int_t^{t+\tau}\int_t^{t+\tau} h_{d_q}(\tau, t+\tau-\mu)h_{d_q}(\tau, t+\tau-\alpha)[\overline{i(\mu)i(\alpha)} - \overline{Q^*(\mu)i(\alpha)}]d\mu d\alpha. \tag{51}$$

Having established the condition for the optimum mean-square prediction of the desired response with an arbitrary weighting factor $\lambda(\mu)$, the implicit condition for the optimum linear filter is developed. The optimum linear approximation to $i(\mu)$ is defined as

$$Q^*(\mu) = \int_{-\infty}^{t} h^*(\mu, \alpha)v(\alpha)d\alpha \tag{52}$$

as opposed to the arbitrary approximation given in Eq. 31. When Eqs. 31 and 52 are substituted in Eq. 49, the result is written as

$$\int_{-\infty}^{t} h(\beta, \gamma) \left[\int_{-\infty}^{t} h^*(\mu, \alpha) \overline{v(\gamma)v(\alpha)} d\alpha - \overline{i(\mu)v(\gamma)} \right] d\gamma = 0. \quad (53)$$

Since $h(\beta, \gamma)$ is the impulse response of an arbitrary linear filter, the following form of the Wiener-Hopf condition results:

$$\int_{-\infty}^{t} h^*(\mu, \alpha) \overline{v(\gamma)v(\alpha)} d\alpha = \overline{i(\mu)v(\gamma)} \quad \text{for} \quad \gamma < t \quad \text{and} \quad \mu \geq t. \quad (54)$$

The explicit description of the optimum linear filter can be determined by the spectral factorization methods of Wiener (1) or by the extensions of Booton (9).

The importance of the condition given in Eq. 54 for the optimum mean-square predictor is that this Wiener filter is completely independent of the dynamic process and the weighting of response errors as specified by the weighting factor $\lambda(\mu)$.

CONCLUSIONS

The class of optimum control systems presented here is very general in terms of the mathematical design methods presently treated in feedback-control literature. This generality can be utilized with the aid of the mathematical concepts of dynamic programming. Even though the emphasis here is placed on an important subclass of systems, the formulation has been presented for an error criterion of unspecified form in order that both the conceptual and the computational simplifications associated with each mathematical restriction can be identified.

The formulation of adaptive control systems develops two important concepts of control theory which are not delineated by the methods associated with Wiener's filter theory. First, there is an optimum configuration of the control system which is dictated by the incidence of disturbances in the system. Second, an estimation of the desired response and control variables of the dynamic process is required everywhere on the interval of future time where response errors are weighted. On the other hand, if the system has no dynamic limitations as specified by an infinite range of the control variable and by an infinite weighting factor λ, no estimation of the future values of the desired response and control variables is required.

Finally a number of significant applications of the separable class of adaptive control systems have occurred in both military and industrial fields (10, 11). The success of these systems primarily is attributed to use of the optimum configuration and to the flexibility in response characteristics attained by the proper choice of the form of the weighting factor λ.

Acknowledgment

This work is based on an extension of doctoral thesis research in the Electrical Engineering Department of the Massachusetts Institute of Technology. The research was supported in part by the International Business Machines Company under IBM Purchase Order No. L-R 19014, and under the Massachusetts Institute of Technology DSR Project No. 7793.

The author is indebted to the staff of the Servomechanisms Laboratory at M.I.T., who have criticized the development of this work. Also special recognition is due to Dr. Philip M. Lewis, Assistant Professor of Electrical Engineering at the Massachusetts Institute of Technology, and Dr. Stanley E. Rauch, Professor of Applied Mathematics at the University of California, who provided much of the encouragement necessary to complete this work.

GLOSSARY

$a_u(t)$, $b_u(t)$	coefficients in linear dynamic process
e	error criterion
$e_{dq}(t)$	error in director output due to the errors in predicting the desired response variable.
$E[z^{(U-1)}(\mu), \cdots, z(\mu); \mu]$	minimum error function for U^{th} order dynamic process
$f_m(x)$	function which defines the criterion used for weighting process input errors
$f_q(x)$	function which defines the criterion used for weighting process response errors
$h_n(\alpha)$	linearly independent solution of the homogeneous differential equation associated with the impulse response $h(\mu, \alpha)$
$H_n(\mu)$	a parameter of the impulse response $h(\mu, \alpha)$
$h(\mu, \alpha)$	impulse response of linear estimator
$h_{dq}(\tau, t+\tau-\mu)$	impulse response of director equations
$i(\alpha)$	exact prediction of the desired process response
$K(\mu)$, $K_u(\mu)$, $K_{uv}(\mu)$	parameters of the minimum error function
$\mathcal{K}_n(t, \tau)$	no-energy storage gain computed from the director equations
$L^-(\sigma)$, $L^+(\sigma)$	limits on the magnitude of the variable $z^{(U)}(\sigma)$
$\mathcal{L}[z^{(U)}(\sigma)]$	abbreviation for $L^-(\sigma) \leq z^{(U)}(\sigma) \leq L^+(\sigma)$
$m(t)$	input variable of the dynamic process
$M(\sigma)$	best available estimate of the desired process input
n	dummy index of summation
N	order of linear estimator
$q(t)$	response variable of the dynamic process
$Q(\sigma)$	best available estimate of the desired process response
$Q_n(t)$	response of a first order linear filter
t	present time
u	dummy index of summation
U	order of the dynamic process
v	dummy index of summation
$v(\alpha)$	signal which contains an additive component $i(\alpha)$
$z(t)$	state variable of the dynamic process
$\alpha, \beta, \gamma, \zeta, \mu, \sigma$	dummy time variables
δ	parameter

ϵ	arbitrarily small increment of time
$\eta(\mu)$	arbitrary variation
$\lambda(\sigma)$	weighting factor
τ	interval where process response errors are weighted
Superscripts:	
(u)	u^{th} derivative of variable with respect to a time variable
*	optimum in the mean-square sense
Subscripts:	
μ	partial derivative of function with respect to the dummy time variable μ
(u)	partial derivative of function with respect to the state variable $z^{(u)}(\mu)$

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New Material, Avcoite, for Structural Use Above 5000 F.—A material that can live through the searing blast of a 5,000 F. rocket-engine exhaust, unchanged by heat shock or erosion, has been anounced by Avco Research and Advanced Development Division at Wilmington, Mass. The new material is a specially designed and highly developed reinforced ceramic that resists gas erosion at extreme temperatures and eliminates structural failure due to heat shock. Avcoite is the first of a family of materials being developed at Avco which are basically ceramic in nature using different ingredients in fabrication.

Avcoite can be fabricated for rocket nozzles, nozzle components, and other applications where materials must retain their shape and dimensions at very high temperatures. The Avco scientists state that negligible changes in rocket nozzle throats have resulted at temperatures of 5,000 F. for test durations of more than 60 seconds with actual rocket motors.

Although the actual nature of the material and its method of manufacture cannot be disclosed, the Avco research group also revealed that failure due to heat shock, which has always plagued ceramic structures, has been eliminated. The normally brittle ceramic has been developed in Avcoite to be quasi ductile. Excessive stresses cause Avcoite to deform rather than result in a brittle, catastrophic fracture. And, the scientists say its resistance to the high-temperature gas erosion caused by liquid and solid propellant fuels used in missile propulsion systems, based on rocket tests to date, has been very encouraging.

Avco, holder of Air Force contracts to develop re-entry vehicles for Titan and Minuteman ICBMs, has been carrying out research in materials science and technology. "To design missile components like rocket nozzles, firing chambers, and radones successfully, the development of new materials must maintain long leads over design schedules and anticipate further requirements," according to Dr. E. Scala, Chief of the Materials Section at Avco's Research and Advanced Development Division. Dr. Scala also said, "Integrated efforts in the fields of ceramics, plastics and metallurgy are required in order to extend the materials capabilities needed for future rocket nozzles and other high-temperature applications."

Resisteg Coating.—Resisteg, a new concept in coatings assuring greater stability and longer life for power wire wound resistors, has been announced by International Resistance Company, of Philadelphia. The low curing temperature of Resisteg coating, less than 205 F., enables the resistors to maintain their full rating. IRC's Resisteg coated resistors need no derating, even at high resistance values. This results from the curing operation which does not change the position of the wire. The problem of work-hardening wire has been eliminated, since excessive tension is not necessary to prevent shifting.

The cooling efficiency of any power-wire wound resistor is directly related to the mass of metal within the resistor. The ability to use closely spaced turns of heavier wire in IRC Resisteg coated power-wire wound resistors increases the transfer of heat from the interior of the resistor to the terminals. This reduces hot spot temperatures, dissipates sudden overloads quicker, and keeps the resistor cooler with resulting greatly increased reliability.

IRC power wire wound resistors with Resisteg coating will not crack or craze from aging, thermal shock or internal stress. Resisteg contains no salts which encourage electrolysis and wire corrosion.

TOPOLOGICAL EVALUATION OF NETWORK FUNCTIONS*

BY

WAN HEE KIM[1]

ABSTRACT

This paper considers the topological relationships for the various combinations of two terminal-pair networks that may be useful in analysis as well as in synthesis of networks. These results are obtained by means of topological identities of a two terminal-pair network that contains no transformer. The necessary conditions of the transfer function for the physical realizability are also derived.

Application of the topological formulas to the evaluation of network functions is illustrated with an example.

1. INTRODUCTION

Topological relationships in an electrical network are very useful in the analysis of a network, particularly in the evaluation of network functions when the network contains no transformer.

However, finding all trees in a network with a large number of elements may not be done merely by inspection of the network. Therefore, a network with a large number of elements may be necessarily decomposed into several interconnected sub-networks. Then, one needs to know the topological relationships between the original network and sub-networks. This paper presents the results of investigation of various combinations of two terminal-pair networks, by means of topological identities derived. Application of those topological formulas to network analysis is illustrated with an example.

2. TOPOLOGICAL EXPRESSIONS OF NETWORK FUNCTIONS

The networks considered are linear, passive, and bilateral without mutual coupling.

T = sum of all tree (complete tree) (1)[2] admittance products in a network. A tree admittance product is the product of admittance functions of all branches of a tree. The tree admittance product of a vertex is defined to be unity.

$T^{(abc\cdots)}$ = sum of all tree admittance products in the network derived from the original one with a number of vertices, say vertices a, b, and c, $\cdots$, made coincident. Assume $a \neq b \neq c \neq \cdots$; otherwise $T^{(abc\cdots)} = 0$. For example, $T^{(aab\cdots)} = 0$.

$T^{\underline{(abc\cdots)}(a'b'c'\cdots)}$ = sum of all tree admittance products in the network

* This work was supported by National Science Foundation Grant G-6020.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

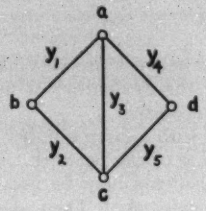
derived from the original one with a number of groups of vertices, say groups of vertices $(abc\cdots)$ and $(a'b'c'\cdots)$ made coincident respectively. Assume $a \neq b \neq c \neq \cdots$; and $a' \neq b' \neq c' \neq \cdots$; otherwise $T^{\overline{(abc)}\,\overline{(a'b'c'\cdots)}} = 0$. For example, $T^{\overline{(aac\cdots)}\,\overline{(a'b'c')}\cdots} = 0$.

$T^{(abc\cdots)\cap(a'b'c'\cdots)}$: sum of all tree admittance products common to both $T^{(abc\cdots)}$ and $T^{(a'b'c'\cdots)}$.

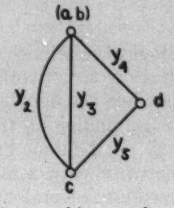
These definitions are illustrated in the following example.

Example 1

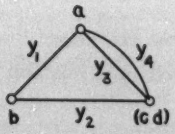
Let a network be given in Fig. 1*a*, and sub-networks derived from the original one with a number of vertices made coincident are shown in Figs. 1*b*, 1*c* and 1*d*, respectively.



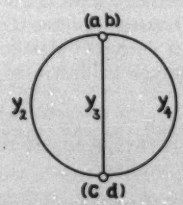
(*a*) Original network



(*b*) Vertices *a* and *b* are made coincident



(*c*) Vertices *c* and *d* are made coincident



(*d*) Two groups of vertices (ab) and (cd) are made coincident, respectively

FIG. 1.

Then, T is the sum of all tree admittance products of the network of Fig. 1*a*, and is given by

$$T = y_1y_2y_4 + y_1y_2y_6 + y_1y_4y_5 + y_1y_3y_4 + y_1y_3y_6 + y_2y_3y_4 + y_2y_3y_6 + y_2y_4y_5.$$

$T^{(ab)}$ is the sum of all tree admittance products of the sub-network of Fig. 1*b*, and

$$T^{(ab)} = y_2y_4 + y_2y_5 + y_3y_4 + y_3y_5 + y_4y_5.$$

$T^{(cd)}$ is the sum of all tree admittance products of the sub-network of Fig. 1*c*, and

$$T^{(cd)} = y_1y_2 + y_1y_3 + y_1y_4 + y_2y_3 + y_3y_4.$$

$T^{(ab)\cap(cd)}$ is the sum of tree admittance products common to both $T^{(ab)}$ and $T^{(cd)}$, and

$$T^{(ab)\cap(cd)} = y_2y_4.$$

$T^{\underline{(ab)}\,\underline{(cd)}}$ is the sum of all tree admittance products of the sub-network of Fig. 1*d*, and

$$T^{\underline{(ab)}\,\underline{(cd)}} = y_2 + y_3 + y_4.$$

Finally,

$$T^{(abcd)} = 1 \qquad \text{by definition.}$$

Again, let

Δ = the node determinant of the given network.
Δ_{ij} = the cofactor of the node determinant for the (i, j) position.
$\Delta_{\substack{ij \\ kl}}$ = the algebraic complement of the second-order minor of the node determinant.

Then, it is well known that (**1, 2, 3, 4, 5**)

$$\Delta = T$$

$$\Delta_{ij} = \begin{cases} T^{(ri)} & \text{for } i = j \\ T^{(ri)\cap(rj)} & \text{for } i \neq j \end{cases} \tag{1}$$

where the r^{th} vertex is the reference vertex of the given network. It can also be verified that

$$\Delta_{\substack{ij \\ kl}} = \begin{cases} T^{(rik)} & \text{for } i = j, \text{ and } k = l. \\ T^{(rik)\cap(ril)} & \text{for } i = j, \text{ and } k \neq l. \\ T^{(rik)\cap(rjk)} & \text{for } i \neq j, \text{ and } k = l. \\ T^{(rik)\cap(rjl)} & \text{for } i \neq j, \text{ and } k \neq l. \end{cases} \tag{2}$$

Using the notations defined, and Eqs. 1 and 2, the following identities are obtained. The proofs for the identities are given in Appendix I.

Identities

1. $T^{(ri)} = T^{(ri)\cap(rj)} + T^{(ri)\cap(ij)}$
2. $T^{(ij)} = T^{(ri)\cap(ij)} + T^{(rj)\cap(ij)}$
3. $T^{(rij)} = T^{(rij)\cap(rik)} + T^{(rij)\cap(ijk)}$
4. $T^{(ijk)} = T^{(rij)\cap(ijk)} + T^{(rjk)\cap(ijk)}$
5. $T^{(ij)} \cdot T^{(ik)} - [T^{(ij)\cap(ik)}]^2 = TT^{(ijk)}$

6. $T^{(ijk)} \cdot T^{(ij)} - [T^{(ijk)\cap(ijl)}]^2 = T^{(ij)} T^{(ijkl)}$

7. $T^{(ij)} + T^{(ik)} - 2T^{(ij)\cap(ik)} = T^{(jk)}$

8. $T^{(ijk)} + T^{(ijl)} - 2T^{(ijk)\cap(ijl)} = T^{\underline{(ij)}\,\underline{(kl)}}$.

Network functions of two terminal-pair networks are expressible with topological relationships by using the identities listed above.

The system equation of a two terminal-pair network, shown in Fig. 2, is given,

$$\begin{bmatrix} V_{10} \\ V_{23} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} \Delta_{11} & \Delta_{12} - \Delta_{13} \\ \Delta_{12} - \Delta_{13} & \Delta_{22} + \Delta_{33} - 2\Delta_{23} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{3}$$

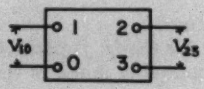


FIG. 2. Two terminal-pair network.

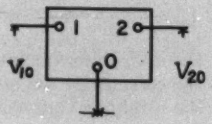


FIG. 3. Three-terminal network.

where the vertex 0 is the reference vertex. Then, the open- and short-circuit immitance functions are found as:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \frac{1}{T} \begin{bmatrix} T^{(10)} & T^{(10)\cap(20)} - T^{(10)\cap(30)} \\ T^{(10)\cap(20)} - T^{(10)\cap(30)} & T^{(23)} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \frac{1}{T^{\underline{(10)}\,\underline{(23)}}} \begin{bmatrix} T^{(23)} & T^{(10)\cap(30)} - T^{(10)\cap(20)} \\ T^{(10)\cap(30)} - T^{(10)\cap(20)} & T^{(10)} \end{bmatrix}. \tag{5}$$

The transfer function of voltage-ratio is given,

$$\frac{V_{23}}{V_{10}} = \frac{T^{(10)\cap(20)} - T^{(10)\cap(30)}}{T^{(10)}} = \frac{T^{(10)\cap(20)} - T^{(10)\cap(30)}}{T^{(10)\cap(20)} + T^{(10)\cap(12)}}. \tag{6}$$

For a three-terminal network shown in Fig. 3, the system equation is given in Eq. 7

$$\begin{bmatrix} V_{10} \\ V_{20} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} \Delta_{11} & \Delta_{12} \\ \Delta_{21} & \Delta_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}, \tag{7}$$

where the vertex 0 is the reference vertex.

Then, network functions of the three-terminal network are:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \frac{1}{T} \begin{bmatrix} T^{(10)} & T^{(10)\cap(20)} \\ T^{(10)\cap(20)} & T^{(20)} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \frac{1}{T^{(012)}} \begin{bmatrix} T^{(20)} & T^{(10)\cap(20)} \\ T^{(10)\cap(20)} & T^{(10)} \end{bmatrix}. \tag{9}$$

The transfer function of voltage-ratio is given

$$\frac{V_{21}}{V_{10}} = \frac{T^{(10)\cap(20)}}{T^{(10)}} = \frac{T^{(10)\cap(20)}}{T^{(10)\cap(20)} + T^{(10)\cap(12)}}. \tag{10}$$

3. CONDITIONS FOR PHYSICAL REALIZABILITY

Fialkow and Gerst (6) derived a set of necessary and sufficient conditions on the physical realizability of a three- and four-terminal network. That these conditions are necessary can be demonstrated simply by means of the topological relations given in the last section.

Let the transfer function of a voltage ratio for a two terminal-pair network, $G(s)$ be

$$G(s) = \frac{P(s)}{Q(s)} = \frac{a_0 s^m + a_1 s^{m-1} + \cdots + a_m}{b_0 s^n + b_1 s^{n-1} + \cdots + b_n}, \tag{11a}$$

where $P(s)$ and $Q(s)$ have no common factors.

From Eqs. 6 and 10, the transfer function may be rewritten as

$$G(s) = \begin{cases} \dfrac{T^{(10)\cap(20)}}{T^{(10)}} & \text{for three-terminal} \\ \dfrac{T^{(10)\cap(20)} - T^{(10)\cap(30)}}{T^{(10)}} & \text{for four-terminal.} \end{cases} \tag{11b}$$

In Eq. 11*b* every tree admittance product which appears in $T^{(10)\cap(20)}$ or $T^{(10)\cap(30)}$ will also appear in $T^{(10)}$. Therefore, if $T^{(10)}$ has i^{th} order zeros, then $T^{(10)\cap(20)}$ and $T^{(10)\cap(30)}$ will also contain the same order or a greater order zeros. They will, however, be cancelled in numerator and denominator of a transfer function so that the denominator would not contain zero at $s = 0$.

Those tree admittance products which are in common for both $T^{(10)\cap(20)}$ and $T^{(10)\cap(30)}$ will be cancelled out in the numerator of the transfer function of a four-terminal network. Thus no tree admittance product in $T^{(10)}$ will appear more than once in the numerator of a three- or four-terminal network. Therefore, it is clear that the following are necessary for $G(s)$ to be physically realizable with only L, R, and C.

1. $n \geq m$, that is, no pole is at infinity.
2. All coefficients in $P(s)$ cannot be greater than those in $Q(s)$ for the corresponding order in s.
3. No pole is at the origin, that is, $b_n \neq 0$.

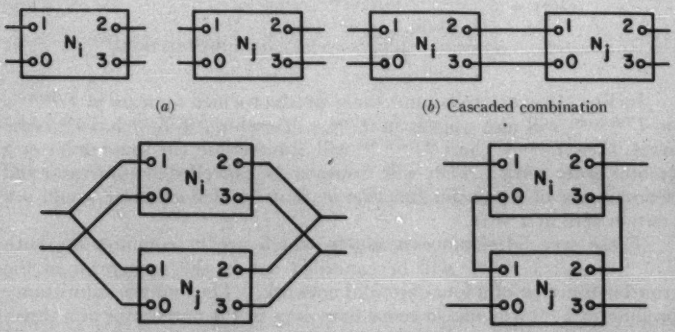
Since Z_{11}, Z_{22}, Y_{11}, and Y_{22} are the driving-point functions of a network, where the vertex 0 is the reference vertex,

4. $\frac{T^{(10)}}{T}$, $\frac{T^{(23)}}{T}$, $\frac{T^{(23)}}{T^{(10)(23)}}$ and $\frac{T^{(10)}}{T^{(10)(23)}}$ are the positive-functions for a four-terminal network.

5. $\frac{T^{(10)}}{T}$, $\frac{T^{(20)}}{T}$, $\frac{T^{(10)}}{T^{(012)}}$, and $\frac{T^{(10)}}{T^{(012)}}$ are the positive-real functions for a three-terminal network.

4. VARIOUS COMBINATIONS OF TWO TERMINAL-PAIR NETWORKS

The topological formulas, shown in the previous section, may not be directly applicable to the evaluation of network functions, since the number of trees in a network may increase rapidly as the number of elements increases. Therefore, it may be necessary that a network with a large number of elements be decomposed into several interconnected sub-networks so that trees in each sub-network may be picked merely by inspection. In doing so, one needs to know the topological relationships between the original network and each sub-network. Therefore, various combinations of two terminal-pair networks are investigated for cascaded, parallel, and series connection, as shown in Fig. 4.



(*a*) (*b*) Cascaded combination

(*c*) Parallel combination (*d*) Series combination

FIG. 4.

Cascaded Connection (*Fig. 4b*)

There is a well-known relationship in cascaded connection of m networks as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \prod_{i=1}^{m} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \tag{13}$$

where A, B, C and D are the general circuit parameters.

In terms of tree admittance products, Eq. 13 is rewritten:

$$\frac{1}{T^{(10)\cap(20)} - T^{(10)\cap(30)}} \begin{bmatrix} T^{(10)} & T^{(10)(23)} \\ T & T^{(23)} \end{bmatrix} = \prod_{i=1}^{m} \frac{1}{T_i^{(10)\cap(20)} - T_i^{(10)\cap(30)}} \begin{bmatrix} T_i^{(10)} & T_i^{(10)(23)} \\ T_i & T_i^{(23)} \end{bmatrix}. \tag{14}$$

Parallel Connection (Fig. 4c)

Let $Y_{i_{11}}$, $Y_{i_{12}}$, and $Y_{i_{22}}$ be the short-circuit admittance functions of a network, N_i. Then:

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{m} Y_{i_{11}} & \sum_{i=1}^{m} Y_{i_{12}} \\ \sum_{i=1}^{m} Y_{i_{21}} & \sum_{i=1}^{m} Y_{i_{22}} \end{bmatrix} \tag{15}$$

or

$$\frac{1}{T^{(10)(23)}} \begin{bmatrix} T^{(23)} & T^{(10)\cap(30)} - T^{(10)\cap(20)} \\ T^{(10)\cap(30)} - T^{(10)\cap(20)} & T^{(10)} \end{bmatrix} = \sum_{i=1}^{m} \begin{bmatrix} \dfrac{T_i^{(23)}}{T_i^{(10)(23)}} & \dfrac{T_i^{(10)\cap(30)} - T_i^{(10)\cap(20)}}{T_i^{(10)(23)}} \\ \dfrac{T_i^{(10)\cap(30)} - T_i^{(10)\cap(20)}}{T_i^{(10)(23)}} & \dfrac{T_i^{(10)}}{T_i^{(10)(23)}} \end{bmatrix}. \tag{16}$$

Series Connection (Fig. 4d)

Since there is no explicit relationship available in network functions for the series connection of two terminal-pair networks, the topological formulas are developed for a pair of two terminal-pair networks connected in series, and then they are extended to the series connection of m networks.

Let us consider a pair of two-terminal pair networks connected in series, as shown in Fig. 4*d*. Then, the following relationships are obtained, and their proofs are given in Appendix II.

(*a*) $T = T_i T_j^{(12)} + T_i^{(03)} T_j$

(*b*) $T^{(10)} = T_i T_j^{(012)} + T_i^{(013)} T_j + T_i^{(10)} T_j^{(12)} + T_i^{(30)} T_j^{(10)} - 2T_i^{(10)\cap(30)} T_j^{(10)\cap(12)}$

$$(c)\quad T^{(20)} = T_i T_j^{(012)} + T_i^{(028)} T_j + T_i^{(20)} T_j^{(12)} + T_i^{(30)} T_j^{(10)} - 2T_i^{(20)\cap(30)} T_j^{(10)\cap(12)}$$

$$(d)\quad T^{(30)} = T_i T_j^{\underline{(12)}\,\underline{(30)}} + T_i^{(30)} T_j^{(30)} \tag{17}$$

$$(e)\quad T^{(12)} = T_i^{(12)} T_j^{(12)} + T_i^{\underline{(12)}\,\underline{(30)}} T_j$$

$$(f)\quad T^{\underline{(12)}\,\underline{(30)}} = T_i^{\underline{(12)}\,\underline{(30)}} T_j^{\underline{(12)}\,\underline{(30)}}.$$

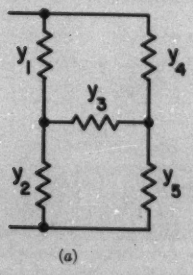
Using Eqs. 17 and Identities in Section 2, $T^{(28)}$, $T^{(312)}$, $T^{(013)}$ and $T^{\underline{(10)}\,\underline{(23)}}$ may be obtained. Next, N_i and N_j are again considered as the networks consisting of two sub-networks connected in series, and the sum of tree admittance products in N_i and N_j or in networks derived from them with some of the vertices made coincident, are obtainable from their sub-networks. Thus, Eqs. 17 can be extended to m networks connected in series.

When a sub-network, N_i, is three-terminal, then

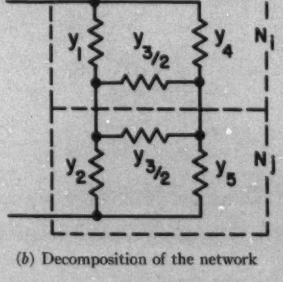
$$T_i^{\underline{(12)}\,\underline{(30)}} = 0, \quad T_i^{(013)} = 0, \quad T_i^{\underline{(10)}\,\underline{(23)}} = T_i^{(012)}, \quad \text{and} \quad T_i^{(30)} = 0 \tag{18}$$

in Eqs. 14, 16 and 17.

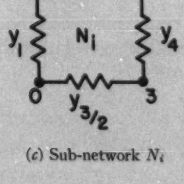
An example is given to illustrate the application of those topological formulas derived to the evaluation of network functions.



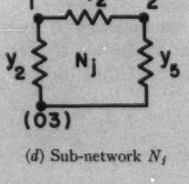
(a)



(b) Decomposition of the network



(c) Sub-network N_i



(d) Sub-network N_j

FIG. 5.

Example 2

Given a network of Fig. 5*a*, find the driving-point impedance function. The given network is considered as two networks being connected in series, as shown in Fig. 5*b*.

From Eqs. 17,

$$Z(s) = \frac{T_i T_j^{(012)} + T_i^{(012)} T_j + T_i^{(10)} T_j^{(12)} + T_i^{(20)} T_j^{(10)} - 2T^{(10)\cap(20)} T_j^{(10)\cap(12)}}{T_i T_j^{(12)} + T_i^{(00)} T_j},$$

where

$$T_i = y_1y_3/2 + y_4y_3/2 + y_1y_4 \qquad T_j = y_2y_3/2 + y_5y_3/2 + y_2y_5$$
$$T_i^{(10)} = y_4 + y_3/3 \qquad T_j^{(12)} = y_2 + y_5$$
$$T_i^{(20)} = y_1 + y_4 \qquad T_j^{(012)} = 1.$$
$$T_i^{(012)} = 1$$

Then $Z(s) = A(y)/B(y)$, where

$$A(y) = y_1y_3 + y_1y_4 + y_1y_5 + y_2y_3 + y_2y_4 + y_2y_5 + y_3y_4 + y_3y_5$$
$$B(y) = y_1y_2y_3 + y_1y_2y_4 + y_1y_2y_5 + y_1y_3y_5 + y_1y_4y_5 + y_2y_3y_4 + y_2y_4y_5 + y_3y_4y_5.$$

The topological relationships, derived thus far for the series, parallel, and cascade connection of two terminal-pair networks, can be applied to the compound connection of networks, where each sub-network is required to be either two-, three-, or four-terminal. The decomposition techniques presented here may also be useful in synthesis problems as illustrated in reference 7.

APPENDIX I

Proofs for the identities are given.

Proof for Identity: $T^{(ir)} = T^{(ir)\cap(jr)} + T^{(ir)\cap(ij)}$

Let the node-determinant of a network be

$$\Delta = \begin{vmatrix} y_{11}, & \cdots, & -y_{1k}, & -y_{1i}, & -y_{1j}, & \cdots, & -y_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ -y_{n1}, & \cdots, & -y_{nk}, & -y_{ni}, & -y_{nj}, & \cdots, & y_{nn} \end{vmatrix}.$$

Then, the cofactor for the (i, i) position is

$$\Delta_{ii} = T^{(ri)} = \begin{vmatrix} y_{11}, \cdots, -y_{1k}, -y_{1i}, -y_{1k}, \cdots, -y_{1n} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{k1} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{i1} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{k1} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{n1} \cdots\cdots\cdots\cdots\cdots\cdots y_{nn} \end{vmatrix}$$

$$= \begin{vmatrix} y_{11}, \cdots, -y_{1k}, (y_{1r} + y_{1i}), -y_{1k}, \cdots, -y_{1n} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{k1}, \cdots, y_{kk}, (y_{kr} + y_{ki}), -y_{kk}, \cdots, -y_{kn} \\ -y_{i1}, \cdots, -y_{ik}, (y_{ir} + y_{ii}), -y_{ik}, \cdots, -y_{in} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{n1}, \cdots, -y_{nk}, (y_{nr} + y_{ni}), -y_{nk}, \cdots, y_{nn} \end{vmatrix}$$

$$= \begin{vmatrix} y_{11}, \cdots, -y_{1k}, y_{1i}, \cdots, -y_{1n} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{k1}, \cdots, y_{kk}, y_{ki}, \cdots, -y_{kn} \\ -y_{i1}, \cdots, -y_{ik}, y_{ii}, \cdots, -y_{in} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{n1}, \cdots, -y_{nk}, y_{ni}, \cdots, y_{nn} \end{vmatrix} = \begin{vmatrix} y_{11}, \cdots, -y_{1k}, y_{1r}, \cdots, -y_{1n} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{k1}, \cdots, y_{kk}, y_{kr}, \cdots, -y_{kn} \\ -y_{i1}, \cdots, -y_{ik}, y_{ir}, \cdots, -y_{in} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ -y_{n1}, \cdots, -y_{nk}, y_{nr}, \cdots, y_{nn} \end{vmatrix}$$

$$= \Delta_{ii} + \Delta_{ri}'$$

where Δ' is the node-determinant of the same network with the i^{th} vertex as its reference vertex. Therefore, from Eqs. 1 and 2, one has

$$\Delta_{ii} = T^{(ir)n(jr)}, \qquad \text{and} \qquad \Delta_{ri}' = T^{(ir)n(ij)};$$

hence the identity.

The rest of the Identities can be proved by a process similar to that used for the proof of Identity 1. Some of the identities can be derived in terms of two-tree admittance products (5).

APPENDIX II

Two networks, N_i and N_j, are connected in series as shown in Fig. 4*d*. Consider the vertices 1 and 2 of N_i as the pair of input vertices of the resultant network, N, and the vertices 3 and 0 as the output vertices of N. Then, networks N_i and N_j may be regarded to be connected in cascade; therefore, one obtains

$$\begin{bmatrix} T^{(12)} & T^{(12)(30)} \\ T & T^{(30)} \end{bmatrix} = \begin{bmatrix} T_i^{(12)} & T_i^{(12)(30)} \\ T_i & T_i^{(30)} \end{bmatrix} \begin{bmatrix} T_j^{(12)} & T_j^{(12)(30)} \\ T_j & T_j^{(30)} \end{bmatrix}.$$

Hence, T, $T^{(30)}$, $T^{(12)}$, $T^{(12)(30)}$ are found as shown in Eq. 17.

Next, let the node-determinants of networks N_i and N_j be Δ_i and Δ_j, where the vertex 0 is the reference vertex. Then, Δ_i and Δ_j are given as

$$\Delta_i = \begin{vmatrix} a_{11} \cdots -a_{1n} \\ \cdots\cdots\cdots \\ -a_{n1} \quad\quad a_{nn} \end{vmatrix}$$

$$\Delta_j = \begin{vmatrix} b_{11} \cdots -b_{1m} \\ \cdots\cdots\cdots \\ -b_{m1} \cdots\quad b_{mn} \end{vmatrix}.$$

Then, the node-determinant, Δ of the resultant network N is

$$\Delta = \begin{vmatrix} a_{11}, & \cdots & -a_{1n}, & -a_{13}, & & -a_{10}, & & & \\ \cdots & \cdots & \cdots & & & \vdots & & 0 & \\ -a_{n1}, & \cdots & a_{nn}, & -a_{n3}, & & -a_{n0} & & & \\ -a_{31}, & \cdots & -a_{3n}, & (a_{33}+b_{22}), & & -(a_{30}+b_{21}), & -b_{23}, & \cdots & -b_{2m} \\ -a_{01}, & \cdots & -a_{0n}, & -(a_{03}+b_{12}), & & (a_{00}+b_{11}), & -b_{12}, & \cdots & -b_{1m} \\ & & & -b_{32} & & -b_{31} & \cdots & & \vdots \\ & 0 & & \vdots & & \vdots & & & \vdots \\ & & & -b_{m2} & & -b_{m1} & \cdots & & b_{mm} \end{vmatrix}$$

where the vertex 0 of the network N_i is the reference vertex of the network N. The cofactor of the determinant, Δ, for the position of (11) is decomposed as

$$\Delta_{11} = \Delta_i \Delta_{j11}^{22} + \Delta_{i11}^{33} \Delta_j + \Delta_{i11} \Delta'_{j22} + \Delta_{i32} \Delta_{j11} - 2\Delta_{i13} \Delta'_{j02},$$

where Δ' is the node-determinant of N_i where the vertex 1 is the reference vertex. Therefore

$$T^{(10)} = T_i T_j^{(012)} + T_i^{(013)} T_j + T_i^{(10)} T_j^{(12)} + T_i^{(30)} T_j^{(10)} - 2T_i^{(10) \cap (30)} T_j^{(30) \cap (12)}.$$

Hence, Eq. 17b.

By a similar process, Eq. 17*c* can be proved.

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Hypervelocity Instrumentation Aids ICBM Nose Cone Design.—Hypervelocity instrumentation has been developed by Avco Research and Advanced Development Division, Wilmington, Mass., to measure shock waves, flow patterns, and other events occurring at high Mach numbers in shock tubes and on ballistic ranges. This work is being carried out in connection with the Titan and Minuteman ICBM nose cones which AVCO is developing. AVCO scientists state that hypervelocity instrumentation may be used to study transient phenomena with associated velocities equivalent to those encountered in space travel. To date AVCO has developed a Kerr Cell photographic shutter, a high-intensity light source, a special high-speed Shadowgraph System, and a Catadioptric Light Screen and Amplifier in the field of hypervelocity instruments.

One type of installation is the shadowgraph system used on the AVCO ballistic range. Here the basic shadowgraph system employs a spark-gap point-light source, a collimating lens, a catadioptric light screen, an objective lens, and a photographic plate. A projectile is fired between the two lenses in the collimated light beam. When the projectile is at the center of the optical field it passes through a very sensitive device called a Catadioptric Light Screen used for detecting the presence of the projectile. A photomultiplier in the light screen sends a signal through a video amplifier to a trigger unit which triggers a pulse generator. The pulse generator provides a high-voltage pulse which makes the action of the light source and Kerr Cell mutually synchronized with the position of the projectile. The whole action takes place with a "jitter" of less than 0.1 microsecond.

Using shadowgraph systems AVCO scientists have been able to "freeze" projectiles in flight and study their drag, attitude, and associated flow patterns. Surface detail has also been studied by the addition of an auxiliary light source for front lighting of the projectile. Information gained using these techniques has proven vital in the design of ICBM nose cone shapes.

Exposure times in the range of 10^{-8} and 10^{-7} second are required to prevent image blur in AVCO's work with scaled-down, high-velocity nose cone projectiles. Key to the system is the synchronized pulse generator-light source—Kerr Cell combination. The 2-in. aperture Kerr Cell Shutter is connected directly across the load resistor on the transmission line and, because of this, does not require an impedance matching network.

Kerr Cells and Kerr Cell systems such as employed in shadowgraphs and schlieren systems using AVCO's newly developed hypervelocity instruments are ideal for measuring disturbances in detonation phenomena and flow patterns around projectiles. These systems have also been used to measure spark ignition in fuels, terminal ballistics, response of photosensitive devices, flow patterns in high-intensity plasma generators and rocket motor exhausts, and projectile emergence from gun muzzles.

THE NEGLECTED CAPITAL*

BY

SYDNEY STEELE[1]

Here in the United States we have enjoyed unparalleled opportunities for the development of an industrial economy. About one-hundred and seventy-five million people furnish the world's wealthiest market for industrial products and services. Abundant supplies of raw materials have contributed to the development of large and efficient plants, and a plentiful supply of manpower has been available to manage and operate them. And, when domestic markets could not absorb our full production, our products could almost always be sold in international markets.

Now, for the first time, it appears that our privileged position is being seriously challenged. Other areas in the world are developing their industries on the American pattern, and it is foolish to think that none of them will be able to duplicate our success.

The Asiatic nations, for example, have tremendous potential. Already the Japanese have become an important factor in many areas of world trade. Departing from their traditional emphasis on inexpensive textiles and novelty items, they are now producing precision instruments, high-quality optical goods, and a wide variety of other desirable and well-made items for the American consumer. Only recently the first shipment of Japanese-made automobiles reached our west coast. All this has taken place in a ten-year period.

It is difficult to imagine what effect the same level of industrial development in China, India, and Asiatic Russia would have on world trade, but we cannot ignore the possibility. These nations are developing their industries, and in years to come will play an important part in international trade. Their combined "captive" market must exceed one billion persons.

Latin America, too, will be a factor in future world competition. Up to the present, most industrial development there has been made possible by the help of British, German, and United States capital and industrial know-how. But, as these Latin American nations progress toward economic maturity, we can expect them to stand on their own feet industrially, and to provide new competition for American industry in world markets. The Latin American "captive" market consists of about 115 million persons.

And there is always Russia, with its "captive" market (excluding

* Presented at The Franklin Institute during a luncheon meeting held October 21, 1958.

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Asiatic Russia) of over 144 million persons, and its growing industrial potential.

These developments, however, are some distance in the future. At the present moment, there is a more serious threat to the privileged competitive position of the United States. This threat comes from the recent linking of the economies of most of the nations of Western Europe into a single market area. This market area is the second richest in the world, second only to our own.

What is happening in the new Europe? First of all, there is the European economic community or the European common market, as it is sometimes called. It includes six countries: France, West Germany, Italy, Belgium, The Netherlands, and Luxemburg.

Today the combined population of these countries is 161 million—almost as large as that of the United States. Within ten to fifteen years all of these 161 million people, their money and their goods will be able to move throughout the common market area with no more restrictions than we have on similar movements within our 49 states. And this is just the beginning.

Six other nations are expected to join those of the initial common market, to form a free-trade area that will include Great Britain, Denmark, Norway, Sweden, Switzerland, and Austria. Within that free-trade area, with 240 million people, industrial products will move freely, although agricultural products will be subject to some restrictions.

To illustrate what this means, let us look at the manufacturer of a product that we shall call "X." ("X" might be that ideal product which could be made for a dime, sold for a dollar, and was habit-forming.) The American manufacturer of product "X" will think in terms of a market based on a population of 175 million persons. If he can raise sufficient capital and put together a large enough sales force, he can build a very few, large, efficient plants to make product "X." He will consider the sources of his raw materials and energy, the markets in which he will sell his product, and the areas where people have the skills he will need in his plants. When he decides on a location for a particular plant, he will strike a balance that will make the most efficient use of manpower, raw materials, energy, and transportation in relation to his market.

The comparative freedom of movement of people, raw materials, products and money have been major factors in helping the United States to develop some of the world's most efficient industrial units.

Now, by way of contrast, consider the situation which has confronted the French manufacturer of product "X" up to the time the European common market was formed. First of all, restrictions on the movement of finished product "X" meant that he had to locate the plant in France if he wanted to sell product "X" there. This may have been far from the most efficient location from the standpoint of the

distance he had to bring his raw materials, or the type of people he needed to operate his plant. The greatest handicap he faced was the fact that he had to think in terms of only 43 million people, compared to our 175 million. He may, therefore, have had to build his plants smaller and less efficient.

The European common market will, within the next few years, end these artificial restrictions on industrial efficiency. As a result, the European manufacturers will be able to compete on apparently equal terms with the American manufacturer. In some areas, however, the European will have definite advantages.

For example, the free-trade area of western Europe will include, eventually, 240 million people—a much larger potential market than the United States has. From 1950 to 1955 European industry grew faster than American industry, and the organization for European economic cooperation recently published a study showing that this rapid growth will continue at least until 1960.

With the artificial restrictions removed, we can expect this rapid growth to continue beyond 1960. Even though Europe is the world's second richest market, they still lack many of the things which we take for granted here. Average personal consumption in the United States is in the neighborhood of $1,400 per year. For each person in the nations comprising the European common market, it averages less than $700 annually.

When the artificial restrictions on industrial development are removed, we can expect European industry to expand rapidly as Europeans increase their demands for telephones, refrigerators, automobiles, and other consumer products and services. As the new and more efficient production units of Europe come on stream, we can expect more and more of their products to compete directly in world trade with the products of American factories. With both Europe and the United States operating at a high level of industrial efficiency, the competition in world markets will be severe.

Accustomed as we are to competition in this country among companies, we will have to adjust to far stronger competition from abroad. This situation will be unlike anything we have seen before.

But population is not Europe's sole advantage in the coming competitive clash. Even more serious from our standpoint is the fact that many of the basic ideas and discoveries that American industry has exploited have been European in origin. In years past, European industry has been too restricted to make effective use of these discoveries, for reasons noted earlier. Our ability to supply capital, plus large-scale manufacturing know-how, plus a large "captive" market, has enabled us to benefit from European inventions.

Let us consider just a few of the European ideas that we have commercialized successfully through our American production system.

For example, practically all of our railroad trains are today drawn by Diesel engines—a German invention. Interestingly enough, the steam engines the Diesels replaced were based on a British invention. Many of the basic ideas in the chemical industry have come from Europe. Four of the leading synthetic fibers were developed as a result of European basic research—viscose in France, acetate in Germany, polyvinylidene chlorides such as Saran in Germany, and polyesters such as terylene and Dacron in England. Only the polyamides (for example, nylon) and acrylics (for example, Orlon and Acrilan) can be credited to American basic research. Polyethylene—which is so popular for noiseless trash cans and squeeze bottles, among other uses—and the newer polyolefins came from England, Germany, and Italy. Polyurethane foams—available in both flexible and rigid forms for a wide variety of uses—were developed in Germany. Penicillin, the forerunner of a host of antibiotics, was British in origin, and of fifty "wonder drugs" in current use, only two were developed here. The groundwork in nuclear physics was done by Europeans. Television broadcasts started in England in 1934. Europe invented radio.

Another good example is the automobile, which is basically a European idea. American mass production skills have made us the world's largest producers, but practically all of the fundamentally new automotive engineering developments have come from Europe, and, in general, we are five to ten years behind the European achievement. European industry, operating even under its present restrictions, is finally making in-roads even into the American market. Everyone has seen the growing numbers of small, easily-handled, economical European cars on the roads today. They are even more noticeable along the curb when you discover that what appears to be an empty parking place is occupied by one of them. The competitive situation faced by the American automobile industry has led some of our American manufacturers to import the European-style cars made by their subsidiaries overseas. Perhaps the Europeans have discovered a new American automobile market that Detroit had overlooked.

About a year ago it became clear that Russia had, at least in one field, beaten us at our own game of making practical use of scientific discoveries. There are currently some soothing comments being made about our having "caught up" again, but some skepticism may be in order.[2]

These examples show the extent of the problem we face now, and will face increasingly in the future. In the past, Europe has shown that it can create commercially usable ideas, and it has the imagination and marketing ability to exploit them. All that it has lacked to compete successfully with the United States have been large and efficient

[2] Since this talk was delivered, we have had the "Talking Atlas"—followed by the first man-made planetoid.

productive facilities. Now the European common market and free-trade area will enable them to challenge us even here.

Can we meet this new challenge? We can, but it means a new approach toward utilizing our resources.

What do we have? First there are our non-renewable mineral resources such as iron and coal, and the renewable resources such as timber and agricultural products. Secondly, we have energy sources, including both fossil and agricultural fuels, water power, nuclear energy and sunlight. Thirdly, we have manpower. And, most important of all is our fourth resource—brainpower.

Our chemists, physicists and engineers have made great progress in determining the most effective methods of utilizing raw materials and energy. While there is still room for improvement here, we can expect that our European colleagues will be just as successful as we are in making the most efficient use of these resources. If we are to compete successfully with the new European industry, we must obviously make full use also of our manpower and of our brainpower.

Of these two assets, by far the more important for the long haul is brainpower—and this is the neglected capital of my talk. (We are not neglecting manpower to anything like the same extent, although our use of that resource is less than efficient.)

How then, are we neglecting this capital asset, the brainpower of our youngsters?

In our schools, for the most part, curricula, and the pace at which the student is led through them, are geared to the average mind and the slowest learner. Our desperate need is for an educational program that will give every talented child a challenge to his superior mind. No sentimental regard for a non-existent equality of brain power should permit us to overlook the fact that all of the world's advances have resulted from the efforts of less than one per cent of the people.

Starting about 25 years ago, basic educational courses have been gradually elbowed out of many curricula by so-called life-adjustment courses. Included now are courses on how to drive an automobile, whether the horizontal or vertical movement is to be preferred in tooth-brushing, group dynamics (whatever that may mean), how to choose a family doctor, how to behave on a date, and so on.

It is now possible, in some parts of the country, for a student to graduate from high school without having had any mathematics at all during the four years of high school. And, some years ago, I was surprised to find that credit could be obtained in one of our universities by taking an undergraduate course in relaxation.

It may be pure coincidence, but after 25 years of "life-adjustment" the number of mentally ill, relative to the total population, is, I believe, at an all-time peak.

"Discipline" has become a naughty word. The *New Yorker* cartoon

of some months ago pointed up a new attitude to behavior in some schools. The principal is interviewing a little monster and his mother. The principal says: "Mrs. Minton, there's no such thing as a bad boy. Hostile, perhaps. Aggressive, recalcitrant, destructive, even sadistic. But not bad." The pendulum can swing both ways, however. There is the other story, about the four-year-old who trudged into his modern kindergarten class the other day and said to his teacher: "Do I have to do what I want to do again today?"

We have seen also the development of anti-intellectualism. This is perhaps best illustrated by the President's committee on education beyond the high school. Although this committee stated that our ideals and the increasing complexity of our civilization require that each individual develop his or her talents to the fullest, it went on to say that we will never tolerate the nurturing of an educational élite. Yet we tolerate the nurturing of élites of stage, screen, television, radio, and sports. Why should we not give equal recognition to brains?

Over-all, our educational system may currently be preparing its graduates for a world in which "all is for the best in the best of possible worlds," instead of one in which ability to compete and survive may well be paramount. (There are, however, many individual systems in the U. S. that can be counted among the best anywhere.)

The attitudes and beliefs of American students also have changed, as might be expected.

For over a year Dr. Philip E. Jacob, Professor of Political Science at the University of Pennsylvania, studied surveys and self-analyses from some fifty college and university campuses, and many reports about student attitudes. He concluded that hardly anything fundamental happens to the college student. The college experience barely touches his standards of behavior, quality of judgment, sense of social responsibility, perspicacity of understanding of himself or others, or his guiding beliefs and attitudes. Dr. Jacob added that the students are gloriously contented, both in regard to their day-to-day activity and their outlook for the future. And he felt that the great majority were unabashedly self-centered. They intended to look out for themselves first, and expected others to do likewise. More important, Dr. Jacob found that standards are generally low in regard to academic honesty, systematic cheating being the custom rather than the exception in many major institutions.

The main over-all effect of higher education upon student values was to bring about conformity to a body of standards and attitudes. He did find that some small private colleges sometimes offered a climate favorable to a redirection of values, which is, or should be, one of the objectives of higher education.

Perhaps even more disturbing are the findings reported by William H. Whyte in his recent book, "The Organization Man." From com-

pany to company, Mr. Whyte found that newly-hired graduates expressed the same impatience. All the great ideas, they explain, have already been discovered, not only in physics and chemistry, but in the practical fields like engineering. The basic creative work, they say, is done, so the man you need for every kind of job is a practical, team-player sort of fellow. Said one of them. "I would sacrifice brilliance for human understanding every time."

I've touched briefly on some evidence to show how we are neglecting brainpower, and the findings of Dr. Jacob and Mr. Whyte surely evidence the deplorable effects of our neglect. What can we do to utilize this neglected capital—BRAINPOWER?

I believe we must strengthen our educational system so that, 10 to 15 years from now, we will be graduating students who will have made the most of all of their abilities, whether they are in the liberal arts or scientific fields.

Starting with the belief that the purpose of education is the harmonious development of the mind, the will and the conscience of each individual, so that he may use to the fullest his intrinsic powers, I believe our educational system should insure: (1) that all students without exception receive adequate instruction in the basic intellectual disciplines, particularly English, mathematics, science, history and foreign languages; (2) that the fullest possible opportunity is afforded to students of high ability to reach mature levels of achievement without waste of time; (3) that clear standards of actual accomplishment are used to measure each student's progress, and to govern promotion to higher levels of the educational system; (4) that teachers are thoroughly educated in the subjects they teach and in current developments therein; (5) that vocational training is offered in due subordination to the school's fundamental purpose of intellectual discipline, and that standards of achievement are maintained as rigorously in vocational as in academic fields; and (6) that school administrators are encouraged and supported in resisting pressures to divert school time to activities of minor educational significance, to curricula over-emphasizing social adjustment at the expense of intellectual discipline, and to programs that call upon the school to assume responsibilities properly belonging to the home, to religious bodies, and to other agencies.

Each one of us can do something to further these measures. How?

1. By joining and taking an active part in the PTA, by accepting speaking engagements, by watching local and national legislation concerning education, and by running for membership on the school board.

2. By insisting on meaningful report cards for our children—performance measured in absolute units rather than vague general terms.

3. By instilling in our children the thought that it isn't smart to play it the easy way, and that they had better elect some "difficult"

subjects if they are to have the best chance of survival when they grow up.

You may have seen the full page statement in a recent issue of *Newsweek*, headed "Johnny Had *Better* Learn To Read." Let me read the rest of it: "It no longer matters whether he wants to, or would like to, or *may* learn when the spirit moves him. Johnny now has no choice. He had better learn to read and read well or we may wind up in a world where no English is written any more. Reading is the key to all knowledge, and knowledge is power, and power means survival. Napoleon knew that, and he once said, 'Show me a family of readers, and I'll show you the people who move the world.' We Americans don't want to move the world. But we don't want anyone else to, either. So Johnny had *better* learn to read. Because you can bet Ivan is spending a lot of time on *his* books."

Finally, if I may be permitted a small "commercial" at this point, find out about the Council For Basic Education[3] and, if you are in sympathy with its objectives, become a member and work for better education. The Council's major objective is a strengthening of curricula so that our students may obtain the soundest education afforded anywhere in the world.

We must recognize, however, that the educational problem is receiving careful attention by increasing numbers of professional educators. There are more than 20,000 citizens' groups throughout the country interesting themselves in school problems and Dr. Conant is conducting a two-year survey of the American high school. All of the evidence points to a growing national recognition of our educational needs. But time is running out.

We have seen that Europe, currently the world's second richest market, is moving into a position from which she will challenge us on our own grounds of large and efficient industrial plants geared to supply a very large market. Eventually her "captive" market will be bigger than ours. She has always had a practical monopoly of the basic new ideas that spark our industrial civilization.

Russia has challenged us in the practical applications of advanced rocketry, and can be expected to challenge us also in the world's markets.

To combat this new competition from Europe, from Russia, and from other economic units in the future, we will need to make the fullest use of all of our resources—raw materials, energy, manpower and brainpower.

For the long haul, brainpower is by far the most important. To make fullest use of this, our neglected capital, calls for a significant strengthening of our educational system—now!

[3] 725 Fifteenth St., N.W., Washington, D. C.

ETCH PATTERNS IN ZINC*

BY

VICTOR V. DAMIANO[1] AND MARVIN HERMAN[1]

ABSTRACT

Loops and spiral etch patterns were observed on surfaces parallel or nearly parallel to the basal plane of zinc. Their motion and growth were recorded and appeared similar to the mechanism proposed by Frank and Read (1)[2] for the generation of dislocations. These observations have been tentatively interpreted as the dissolution of a step in the surface with the ends of the steps pinned.

INTRODUCTION

It is believed that many of the experiments producing etch pits in metals and inorganic compounds reveal the ends of dislocation lines protruding through the surface. Comparable experimental evidence of dislocation lines lying in the surface being viewed is limited. Etch patterns suggestive of the latter type were reported by Servi (2) to have appeared on the basal plane of zinc. These patterns were tentatively interpreted as dislocation loops activated by Frank–Read sources; their presence being revealed by impurity atoms segregated at the dislocation line.

In the course of a study of substructures in zinc, loops and spiralled etch patterns (see Fig. 1) similar to those reported by Servi were observed. Experiments at this laboratory involving the cinephotomicrography of the surface of zinc during etching showed the rapid and continuous growth of these patterns (see Figs. 2 and 3). Since this motion could not be expected of dislocations revealed by impurities segregated in their vicinity, an alternate description of the process producing the patterns must be proposed. Thus, the purpose of this paper is to present experimental evidence suggesting that the patterns might more properly be regarded as generated by the dissolution of a step in the surface of the zinc.

EXPERIMENTAL METHOD

Single crystals of zinc (99.998% Zn and 99.9999% Zn) and zinc alloyed with cadmium up to concentrations of 0.07% cadmium were

* This research was supported by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command, under Contract No. AF(600)–1581. Reproduction in whole or in part is permitted for any purpose of the United States Government.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

grown at a rate of 2.2 in. per hour using a Bridgman type furnace. Small sections of crystal were cleaved along the basal plane by first cooling the "as grown" crystal in liquid nitrogen and then carefully tapping a sharp stylus into the surface in a direction approximately parallel to the basal plane. The sections approximately $\frac{3}{8}$ in. in diameter and $\frac{1}{4}$ in. long were mounted with wax onto a microscope slide with the cleavage plane parallel to the plane of the slide. This arrangement

FIG. 1. Etch pattern at high magnification on the basal plane of zinc. (3200×, reduced one half for reproduction.)

permitted the polishing, etching and microscopic examination of the specimen and minimized deformation due to handling. A number of the specimens were deliberately deformed by a hardness indenter and subsequently etched and examined.

The etching behavior of zinc in various solutions composed of CrO_3 and hydrated Na_2SO_4 in water was investigated. Solutions containing 32 grams of CrO_3 and from 1 to 10 grams of hydrated Na_2SO_4 in 100 ml.

of water performed as polishing agents when the specimen was vigorously agitated in them and as etchants revealing loops and spirals when the specimen was allowed to remain stationary in the solutions. Variations in the quantity of hydrated Na_2SO_4 were found to affect the etching characteristics of the surface. The loops and other spiralled etch patterns appeared on the cleavage plane which, in the case of zinc, is the active slip plane, and on surfaces polished approximately parallel to the basal plane.

For the purpose of continuously photographing the surface of the crystal while the etching phenomenon was in progress a 16-mm. motion picture camera was affixed to a microscope (see Fig. 4). The objective

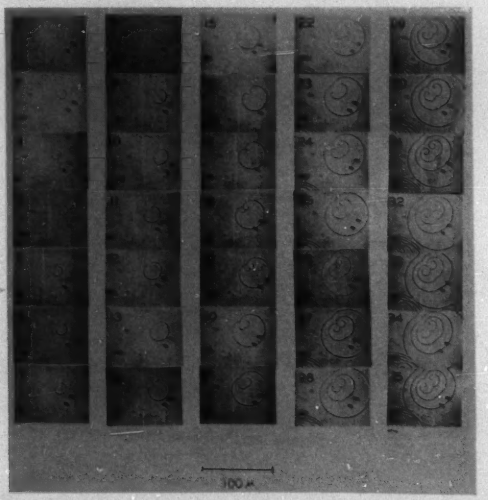

FIG. 2. Cinephotomicrographs showing development of Frank–Read-like etch patterns. (Time sequence of 5 seconds between photomicrographs 1–21 and 10 seconds between 21–35.)

lens of the microscope viewed the specimen through a thin glass window in a cell filled with the etching solution (see Fig. 5). The etch patterns recorded on the motion picture film were magnified 80×. The number of frames of motion picture film exposed per second was controlled by a motor coupled to the camera drive. The speed could be varied so that upon viewing the film at normal projection speeds, the phenomenon progressed at a rate which the eye could readily appreciate. A typical film speed was two frames per second.

During the taking of the movie film the etching was observed visually through a monitoring device coupled between the microscope

and the camera. Continuous focussing of the microscope was required since the etch would, in addition to producing loops and spirals, dissolve the entire surface in a uniform manner. Estimates of this general dissolution were made by measuring the rate at which it was required to rotate the fine focussing knob. After the etching process had developed a series of loops, it was possible to polish them away by gently stirring the solution. When the solution subsided, new loops formed.

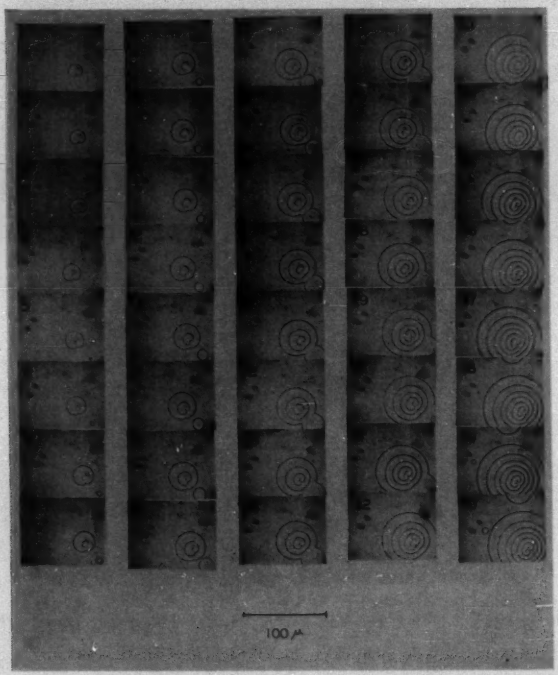

FIG. 3. Cinephotomicrographs showing interaction of Frank–Read-like pattern with a singular pattern. (Time sequence of 10 seconds between photomicrographs.)

It was also possible to interrupt the etching activity by rapidly withdrawing the specimen from the etch, rinsing in water, and drying it. The static patterns which resulted were examined at high magnification on a Zeiss metallograph. Studies were made of the static etching pattern profiles using a simplified interferrometric technique described by Pond and Harrison (3). Sharp shifts in the Newton fringes through the etch patterns made it possible to deduce the contour of the etched surface.

RESULTS

The progressive action of the etch recorded on motion picture film is visually demonstrated in Fig. 2 by the sequence printed from the film. This series shows the C-shaped pattern on the surface and the subsequent growth of this into closed circular loops. Note that the manner in which the expanding loop circles back upon itself, produces a ring, and continues to generate itself bears a strong resemblance to the Frank–Read mechanism for dislocation production. Further similarity is observed in that the ends of the "source" remain relatively fixed in position during the growth of the loop. In samples similar to this where

FIG. 4. Arrangement of the apparatus used showing etching cell, microscope, and camera.

it was possible to polish off the existing loops and start etching anew, it was observed that the positions of the new loops bore no correspondence to the old ones. Figure 3 shows the development of two types of patterns typically encountered on surfaces approximately parallel to the basal plane. In one type, concentric loops develop in a manner similar to an activated Frank–Read source; in the other a single loop appears to develop which does not continue to produce additional rings. Annihilation of a portion of the loops is seen when they interact.

Additional details of the loops are seen in a photomicrograph (see

FIG. 5. Arrangement of specimen in etching cell on stage of microscope.

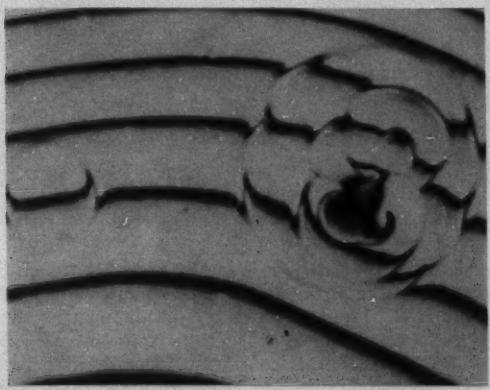

FIG. 6. Etch patterns with superimposed Newton fringes. Shifts in fringes away from center of curvature of the fringes show presence of ridges on the surface. (1430×, reduced one third for reproduction.)

Fig. 1) magnified to 3200×. This is a picture of a specimen interrupted during the etching, removed and examined dry. From observations similar to this it appears that the number of turns of the spirals of the "source" is greater for those in which the distance between the pinning points is greater. Note that each loop in this picture appears to be a ridge on the surface.

Actual topographic profiles of the patterns were derived from Newton ring interferrometry. A typical photomicrograph showing the etch patterns with superimposed Newton fringes is shown in Fig. 6. A fringe shift toward the center of curvature indicates a drop in surface elevation and conversely a shift away from the center indicates a rise in elevation. A profile of the surface contour through a pattern is schematically shown in Fig. 7. Each loop is characterized by a depression

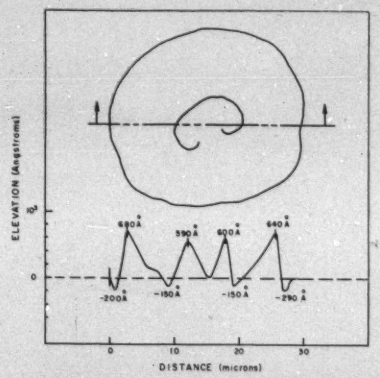

FIG. 7. Typical plot of contour of etch pattern derived from Newton fringe shifts. Horizontal line at 0 elevation is the surface level.

in the surface in the direction in which it is growing. This depression is followed by an abrupt rise in the surface. Note that the change in scale in Fig. 7 between height and distance tends to accentuate the profile disproportionately.

In addition to the nature of the composition of the etch it was found that the condition of the surface also had an appreciable influence upon the etching characteristics. For example, a crystal which was carefully grown and carefully cleaved exhibited sparsely scattered loops after etching, whereas a crudely cleaved crystal exhibited extremely dense and complex patterns. In either case, however, the density of loops was greater at the centers of the specimens than at the edges. Patterns of this sort were also found to develop in the immediate vicinity of hardness impressions placed on the surface (see Fig. 8). An interesting

etching effect was also observed about twins (see Fig. 9). These patterns were asymmetric in nature and the etch markings appeared on one side of the twin trace corresponding to the side of accomodation kinking. Other complex patterns appear at the tip of the twin trace.

Some etching characteristics of polycrystalline samples were also

FIG. 8. Etch patterns formed around hardness impressions on the basal plane of zinc. (2000×, reduced one third for reproduction.)

investigated. Certain differences in the patterns were noted as a function of crystal orientation. When the surface was parallel to the basal plane, the loops formed were nearly perfect circles. Surfaces which were cut at an angle of 10 degrees or greater from the basal plane exhibited half loops which were all oriented in the same manner. This effect is shown in Fig. 10. The polycrystalline sample was initially

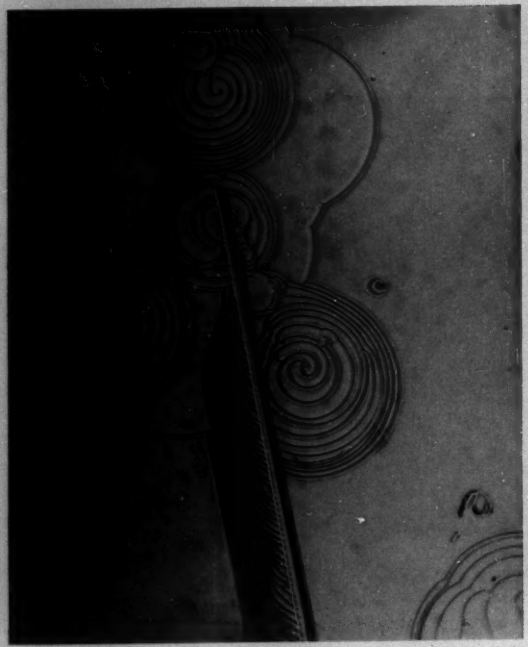

FIG. 9. Etch patterns formed around twin trace on the basal plane of zinc. (2000×, reduced one half for reproduction.)

FIG. 10. Etch patterns observed on polycrystalline specimen. (400×, reduced one half for reproduction.)

polished mechanically and then chemically polished to remove the cold worked surface. The specimen was then etched using the same etching technique previously described for single crystals. The effect of the surface orientation of the etching behavior is clearly shown in the photomicrograph. The basal plane in grain *A* is tilted about 3 degrees from the surface. In grain *B* the angle of tilt is about 30 degrees and

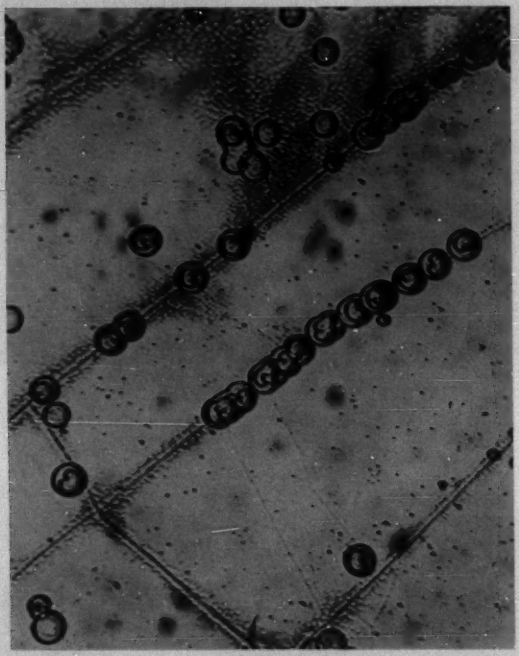

FIG. 11. Basal plane of zinc showing etch patterns nucleated at sub-boundaries. Specimen contains 0.03% cadmium. (400×, reduced one half for reproduction.)

in grain *C* about 20 degrees. Note that the C-shaped patterns opened out in the direction of basal plane tilt and are coherent across the grain boundaries. As the angle of tilt increased the character of the dished-like patterns changed.

Some preferred nucleation of etch patterns was observed. In the first case they appeared at sub-boundaries as shown in Fig. 11. The revealing of sub-boundaries required prior decoration with cadmium. The appearance of the loops is, however, independent of the purity of

the material for loops were readily revealed in 99.9999% pure Tadanac zone refined zinc as well as the C.P. zinc to which 0.05% cadmium had been added. In the second case loops appeared as linear arrays in the very pure materials with no apparent trace of a boundary.

Estimates of the rate of surface dissolution, made using the fine focussing knob of the microscope, are between 3 to 5 microns per minute. This was noted to be of the same order of magnitude as the velocity at which a loop moved across the surface during the etching.

DISCUSSION

Due to the remarkable similarity of some aspects of the etching phenomenon shown in Figs. 2 and 3 and the Frank–Read mechanism proposed for the generation of dislocations, one is immediately tempted to assume that the etch patterns represent dislocation loops lying on an active slip plane in the vicinity of the surface. If these are dislocations and appear because of segregated impurities, it is difficult to see how they could move with impurities at the estimated loop velocity of 5 microns per minute. On the other hand, if it is assumed that the etch can reveal dislocation loops without impurity segregation, it is necessary to show how etching could generate and move loops while the whole surface is dissolving away. This would require the dislocation to climb down into the crystal as the etching progressed and at the same time move in its slip plane under the influence of a stress field set up by the etching process itself. At a rate of removal of material of the order of 5 microns per minute the receding surface should eventually catch up to the relatively slow climbing dislocation and completely remove it from the metal. Contrary to this, the results show that an etched loop persists even after as much as 15 microns of material have been removed.

It might alternately be assumed that the dislocation loops and spirals are stacked and extend down into the crystal. Etching then reveals different sections of the dislocation loops. This mechanism requires that all the loops increase in size as they proceed into the crystal away from the surface. Since there was no correspondence between old and new loops formed on a specimen which was etched, polished, and re-etched, a dislocation network of this stacked and expanding type is not considered possible.

One must logically conclude, therefore, that the growth of the patterns is associated with a surface phenomenon. Since the profiles of the loops obtained from interferrometric work show a depression in the surface at the leading edge of the expanding loops, it is reasonable to think of the process as the etching of steps in the surface. The fact that the general surface is receding requires that these steps proceed both parallel and perpendicular to the surface. As the "source" rotates and produces additional loops, a terraced effect should be produced between each loop. The interferrometric work, however,

indicates that within about 50Å no difference in height between adjacent loops is evident. It is felt that the general dissolution of the surface is a polishing effect which tends to obviate the expected terracing.

Although the growth of the loops appears to be a surface phenomenon not related to any built-in dislocation network, the nucleation of the "source" itself may be determined in part by such a network.

It seems that a depression must appear in the surface for a loop to form. Dislocations lying at or close to the surface may provide the necessary electro-chemical driving force for the etch to dissolve a small linear depression. This line-type depression would be the step that grows and reproduces rings. The fact that the end points of such a step remain fixed suggests that they may be terminated by screw dislocations piercing the surface. A theory proposing the initiation of steps by dislocations is somewhat substantiated by examining regions thought to be heavily populated with dislocations. Numerous observations show that preferred sites for the nucleation of these etch patterns exist at deformed regions around hardness impressions and twins and at sub-boundaries and grain boundaries. Further, the density of loops is greater in the specimens crudely cleaved and in the central portions of all crystals. The etch patterns resembling Frank–Read sources are thus thought to be initiated by dislocations and contained at their ends by screw dislocations.

Since the growth of a pattern is determined by the surface etching, those etch patterns with no Frank–Read source, showing simply an expanding ring, are thought to be initiated by a circular surface depression. The relation of this depression to the presence of a small dislocation loop is speculative.

The interferrometric studies show that a hill follows the dissolution of the step (see Fig. 7). It appears that the etching of a step or groove is accompanied by the deposition of material behind it. The nature of the debris left behind has not been determined but may be in the form of an oxide, redeposited metal or other bi-products of the etching reaction. Small patterns quite similar to these have been observed by Karashima (4) in aluminum polished electrolytically with high current densities. These patterns were considered to represent growth spirals of Al_2O_3 on the crystal surface.

This mechanism seems unlikely in the present work for if an oxide were growing on portions of the surface and the metal surface surrounding the growth layer were being dissolved at a fixed rate, one would expect large steps in the surface where the growth layer of oxide inhibits the dissolution of the metal beneath it. Contrary to this, it is observed that the ridge height remains relatively constant even after 15 to 20 microns of the surface have been removed.

SUMMARY

1. Loops and spiral etch patterns were observed on zinc crystal surfaces which were approximately parallel to the basal plane.

2. Preferential nucleation of the etch patterns occurred at regions of high local deformation such as kink bands, twins, scratches and hardness impressions. Other preferred sites were sub-boundaries and grain boundaries as well as regions at the center of the specimen.

3. The progressive generation of the etch patterns was recorded and appeared similar to the proposed generation of dislocations from a Frank–Read source.

4. Interferrometric studies show that the leading edge of the moving etch pattern is a groove in the surface.

5. These observations suggest the dissolution of a step in the form of a spiral around screw dislocations which pierce the surface and in the form of circles around other surface faults.

Acknowledgment

The authors are grateful to Dr. D. Kuhlmann Wilsdorf of the University of Pennsylvania for helpful discussions and to Mr. G. Stephen Tint for his assistance in preparing, etching, and photographing the zinc crystals.

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Ultrascope, New Aid to Medical and Industrial Research.—A new electron tube, called the "ultrascope," which is expected to be a substantial help in medical and industrial research was demonstrated recently by the Radio Corporation of America.

The tube is the "eye" of a new simple attachment for a microscope, which for the first time allows direct visual focusing of an image under ultraviolet light. It converts invisible ultraviolet images of specimens into visible pictures that can be interpreted quickly by medical research workers in such fields as cancer, arteriosclerosis and viral infections. The accessory replaces the regular eyepiece of a microscope adapted for ultraviolet viewing.

A commercial model of the ultraviolet image-converter unit, equipped for direct viewing and photography, will be made available in the near future by Bausch & Lomb Optical Company of Rochester, N. Y.

This new microscope accessory is expected to be a valuable asset in hospitals, medical schools and biochemical manufacturing. It should also find application in many areas of industrial research for ultraviolet examination of organic materials, including latex, nylon, tobacco, paint and foods, he said.

Cylindrical in shape, the new tube is $2\frac{1}{4}$ in. long and $1\frac{3}{8}$ in. in diameter.

The ultraviolet image-converter tube, which is the "eye" of the device, is the outgrowth of a quarter-century of RCA research and development on image tubes. RCA image-converter tubes, sensitive to infrared rays, were used in the famous "Sniperscope" of World War II and the Korean War. Mounted on gun sights, this device enabled soldiers to see enemy troops and vehicles in total darkness. Until recently, the development and production of image-converter tubes by RCA had been confined to military purposes and was handled in conjunction with the Engineer Research and Development Laboratories, Corps of Engineers, U. S. Army, at Fort Belvoir.

The ultraviolet accessory viewer consists of two units: one, which fits onto the barrel of a microscope, contains the ultrascope and an eyepiece; the other is a compact power supply. A cable connects the power supply to the ultrascope tube.

Invisible rays from an ultraviolet lamp are projected through the specimen under observation, and through an ultraviolet objective lens, thus forming an invisible ultraviolet image of the specimen on the faceplate of the image-converter tube. The faceplate transmits ultraviolet rays and has on its inner surface a photosensitive material which converts the ultraviolet image into a corresponding pattern of electrons, which, in turn, is focused on the fluorescent viewing screen at the opposite end of the tube. The pattern appears on the viewing screen in yellow-green light and is observed through a lens of the desired magnification. Because the human eye is most sensitive to yellow-green light, that color range provides comfortable viewing during prolonged observations.

The unit is also easily adapted to photomicrography and thus can provide film records of the specimen under study.

The Franklin Institute
ANNUAL REPORT
of the Board of Managers for the Year 1958

Summary

The Board of Managers of The Franklin Institute, mindful of its responsibility to cherish the worthy aims of the Founders and, at the same time, to interpret those aims dynamically in terms of today's challenges, is pleased to present this Annual Report for 1958. The past year may well be remembered in history as the beginning of the Space Age. Reviewing the Institute's contributions to science during these past twelve months, the Board is satisfied that in carrying out its primary purpose—"the promotion of the mechanic arts"—the Institute is meeting the challenge of the Space Age just as successfully as its original members solved the problems posed by America's Industrial Revolution.

For more than a century and a quarter, the Institute's activities have been concentrated in three main fields: Education, Professional Aid to Engineers and Scientists, and Research. Although the three programs are not mutually exclusive, they are designed, respectively, for the lay public, for the individual professional man, and for the scientific community.

In carrying out its program of scientific education, the Institute appeals to all age groups through the Museum, through lectures presented at its meetings, and through special events.

Outstanding additions to the Museum during 1958 included the Paper Industry Exhibit, the Hamilton Watch Company's exhibit, "Progress of Time," and several important exhibits which were added to the Bell Telephone Room. The Astronomy Department, in addition to its regular Planetarium shows, sponsored one popular lecture series on astronomy and another, very well attended series of ten semi-technical lectures on astronautics. The latter were published in December as a JOURNAL *Monograph entitled "Ten Steps into Space." The Planetarium staff made valuable contributions to the International Geophysical Year by manning the Moonwatch Station for the gathering of data. They answered innumerable queries on satellites and installed the only monochromator known to be available to the public. This is an instrument for viewing prominences on the sun.*

The Education Division broadened its program for school children by the addition of new lecture-demonstrations, one series of which was called "Science for Little People." The Workshops were expanded to ten-week courses in subjects not taught in the schools.

Of twenty-one lectures presented at Institute meetings during 1958, eight were

on subjects related to the Space Age. Special events during the year included two separate divisions of the Tenth Annual Delaware Valley Science Fair, Science Career Forums for Young People, and temporary exhibits covering patented inventions, rockets and missiles, satellites and the lunar probe.

The Institute continued to provide numerous services to professional scientists and engineers during 1958. In the technical literature field, the Institute not only issues its own JOURNAL, *which last year completed 133 years of continuous publication, but also maintains one of the finest technical libraries in the country. Two symposia brought together professional people for the purpose of exchanging ideas and learning the latest developments in the respective fields of odor control and thermoelectric effects. This second program, although intended for the individual professional man, has become another of those activities which has made The Franklin Institute a revered name in world-wide scientific circles.*

In the category of professional services come the activities of Medal Day at which, in 1958, seventeen individuals were honored for outstanding achievements in science and technology.

By conducting basic and applied research, the Institute fulfills its obligation to the broad scientific community. In addition to The Franklin Institute Laboratories and the Computing Center, both located in the main plant in Philadelphia, the Institute owns and operates the Bartol Research Foundation in Swarthmore, Pennsylvania, and is Trustee for the Biochemical Research Foundation in Newark, Delaware.

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At The Franklin Institute Laboratories, long and short range research projects were carried out, both for the Government and for industry, in such areas as air traffic control, air pollution, missiles, bioengineering, structure of metals, instrumentation, plastics and nuclear reactor design. Among many achievements, one announced publicly by Major General John B. Medaris was the design of certain components of the first successful United States satellite. The Computing Center, established as a separate entity in July, 1958, compiled an impressive record of work performed on the Univac.

At the Bartol Research Foundation laboratory, a new room was built to facilitate study of atomic particles under conditions of very low radioactive background. The cosmic ray program for the International Geophysical Year proved very successful, particularly in regard to the operation of the cosmic ray station at Thule, Greenland. The Biochemical Research Foundation concentrated one phase of its cancer research program on the development of a practical antimutagen screening procedure.

In the matter of finances, despite the general recession, the research activities continued to be self-supporting, although the margin for 1958 was much less than in previous years—indeed, thirty-eight per cent less in net income than in 1957.

The results of operations of the Computing Center were, however, most satisfactory. Because of circumstances which may not recur, we perhaps should not hope for so high a workload in the immediately forthcoming years.

With respect to the educational and general activities, the Institute incurred a deficit nearly three times that of the previous year. While continually increasing

demands on services are most gratifying, the financial strain is always directly proportional and there is only a slight change in general income.

During the year contributions and appropriations were slightly higher than in 1957. Without these funds, the Institute's educational activities would have been seriously curtailed. Nevertheless, it is fully evident that to maintain and further the vitally important educational work for which the community looks to The Franklin Institute, it will be necessary to seek contributions of a very much higher order in the years to come.

This Report would not be complete without a word of tribute to those who are both directly and indirectly responsible for the conduct of the Institute's varied activities. The Board extends its deep appreciation to the members for their interest and support, to the staff for their fine work and particularly for their loyalty, and to the many individual and corporate friends who, through gifts, have materially alleviated the ever-present need for more funds.

The Board of Managers, in presenting this Annual Report for 1958, is gratified by the progress evidenced during the past year in all the Institute's programs of service to science, and is particularly pleased to note that these programs have gone a long way in translating the objectives of the Founders in terms of today's challenging Space Age. To this successful fusion of past and present, The Franklin Institute owes much of its prestige. By continuing to look ahead and to anticipate scientific needs, the Institute will be assured of an unlimited future in the promotion of the mechanic arts. It is our duty to seek—and find—the necessary funds to underwrite this future.

Respectfully submitted,
By order of the Board of Managers,

WYNN LAURENCE LEPAGE
President

January 21, 1959

Education

On the threshold of the Space Age, the current shortage of trained scientists and engineers poses a real threat to progress. Further, faced with the near-fact of travel beyond the Earth's gravity field, the layman desires desperately to understand this totally strange phenomenon. The Institute, in 1958 as in many years past, offered a varied program designed, on the one hand, specifically to awaken young people to the rewards of careers in science, and on the other, to keep the general public informed of the latest developments in technology. Through the Museum and the lectures given at Institute meetings, the Institute performed a Herculean task in keeping abreast of the rapidly expanding space technology.

Museum

The Institute's Science Museum presents a constantly changing panorama of scientific and industrial exhibits, designed to attract both young and old. Permanent displays depict fundamentals of science and modern industrial processes; by means of temporary exhibits, the Museum offers visitors the very new developments, graphically presented for easy understanding. Dur-

School group watching demonstration of Fourdrinier papermaking machine in the new Paper Industry Exhibit.

One section of the loan exhibit prepared by the Patent Office in conjunction with fifteen chemical and synthetics companies to illustrate the importance of patents in a free enterprise economy. (Photo courtesy U. S. Department of Commerce.)

ing 1958, several permanent exhibits were added, the most conspicuous of which were the Paper Industry Exhibit, the completion of the modernization of the Bell Telephone Room, and the exhibit, contributed by the Hamilton Watch Company, "Progress of Time," which includes the Mars Space Clock. Outstanding temporary exhibits included two arranged with the cooperation of the Patent Office—one on the chemical industry and one on the electronics industry. Other loan exhibits, related to the new space technology, were those showing the successful Explorer launching, the Vanguard satellite and the "Pioneer" lunar probe.

The increase in attendance of Museum visitors which had been established in recent years was maintained during the year under review. The comparative figures are:

Museum Attendance

Year	Children *	Adults	Total
1954	209,306	89,088	298,394
1955	219,765	92,248	312,013
1956	238,207	98,063	336,270
1957	263,305	114,304	377,609
1958	275,258	130,601	405,859

* Up to and including those of senior high age.

The practice of exercising a strict supervision over offers of gifts and loans to the Museum has been continued, but nine additions have been gratefully accepted.

Education Division

The prime objective of the Education Division of the Museum is to interest young people in science. In addition to the regular guided tours of Museum facilities, the Division sponsors special lecture-demonstrations. Three such demonstrations were presented in 1958: one on atomic energy in July and August; one on the science of music in November; and a continuing series "Science for Little People." The 19th Annual Latin Week, with two "Roman Festivals," was observed in February, in cooperation with area schools. In the majority of cases, the events were over-subscribed and extra presentations had to be arranged to accommodate the crowds.

In 1958 the Winter and Summer Workshops were expanded to include ten-week courses in astronomy, elementary electronics, photography and instruction in "ham" radio station operation. These courses supplemented, but did not duplicate, work of the schools. Enrollment in the 1958 Workshops was 100 per cent higher than in 1957.

Robert W. Neathery, Director of Museum Education, and Brian DePalma, first prize winner of the Tenth Annual Delaware Valley Science Fair, inspecting his exhibit, "The Critical Study of Hydrogen Quantum Mechanics Through Cybernetics."

The Tenth Delaware Valley Science Fair, co-sponsored by the *Philadelphia Inquirer* and the Institute, proved so popular that for the first time separate Senior and Junior Fairs were held, one in April and one in May.

To encourage young people to elect some phase of science as their life work, the Division cooperates with teachers and with technical societies in the area. On January 25, in conjunction with the Philadelphia Science Council, nearly 100 finalists in the 1958 Philadelphia Talent Search were interviewed by scientists and engineers in Franklin Hall. A Career Forum, co-sponsored with local chapters of the American Institute of Electrical Engineers and the Institute of Radio Engineers, was held in November. In addition, physics teachers in the Area were invited to a counselling session in February to discuss the new high school physics course.

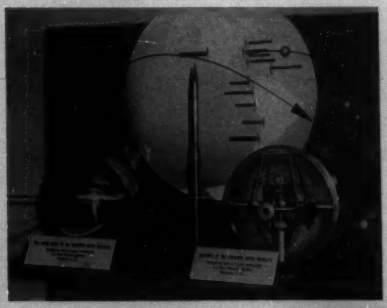
The 33rd James Mapes Dodge Lecture was delivered on October 22 by Dr. Vernet Eaton, of Wesleyan University in Connecticut. His lecture on "Color" was presented twice, to capacity audiences.

For maximum effectiveness of its program, the Education Division enjoys the close cooperation of the public, private and parochial schools in the Delaware Valley.

The Planetarium

The planetarium staff experienced an exhausting yet rewarding year, since they were largely responsible for coping with the public's nearly insatiable demands for knowledge of the satellites, rockets, moon probes and space travel.

In the spring of 1958, a new console was installed in the Planetarium chamber, increasing the versatility of the instrument so that three different shows can be programmed at the same time. New presentations during 1958 were "The American Satellite" and "Astronomy in History." A record attendance of 268,854 during the year indicates the increasing interest in conditions man will encounter in his space travels. Many extra shows had to be arranged to meet the demand.



Full scale model of the Vanguard Earth satellite showing the instruments it carried. (Official United States Navy photograph.)

Air Force exhibit on the Pioneer Lunar Probe.

The Observatory

During the summer, The Franklin Institute Monochromator was assembled and attached to the 10-inch refracting telescope, permitting visitors to view prominences on the sun. One of only about a dozen in the world, this instrument is, to the best of our knowledge, the only one available for public use. Throughout the year, the Institute's Moonwatch Station was in operation for collection of IGY data. In particular, they answered questions concerning visibility of the satellites in this area.

The Franklin Institute Monochromator, only instrument of its kind open to the public.

Astronomy Lecture Series

Two series of lectures were sponsored during 1958. In the spring, ten lectures on astronautics were presented by the foremost men in the field. An average of 300 college students, scientists, engineers and interested laymen attended each lecture. The series covered all phases of space travel, satellites and rockets, in semi-technical language. In the fall, an eight-week course in astronomy was given in the Planetarium by Dr. William M. Protheroe, of the University of Pennsylvania.

Institute Meetings

The Stated Meetings of the Institute and Joint Meetings with engineering and other technical societies brought semi-popular expositions of a wide range of subjects to members and their guests. Ranking authorities addressed gratifyingly large audiences at a total of twenty-one meetings. An outstanding occasion was the appearance of Major General John B. Medaris, Commander of the Army Ballistic Missile Agency, on February 5, when over 800 people in Franklin Hall and the Lecture Hall heard how ABMA had launched the satellite Explorer I only four days earlier.

Lectures in 1958

	Date	Title	Speaker
A	January 15	*Basic Research—Foundation of Steel's Progress Today* *	J. B. Austin
	January 29	*Radio Astronomical Measurements of Interest to Cosmologists*	A. Edward Lilley
	February 5	*Beyond the Air Age*	John B. Medaris
	February 11	*Fire Power*	Harold U. Landis, Jr.
S	February 19	*More Power to Delaware Valley* **	Kilshaw M. Irwin
	February 26	*Sound Slide Program*	James C. Cleary, Jr.
S	March 19	*Fusion Power in the Stars and on the Earth*	Lyman Spitzer, Jr.
	March 26	*Science Is Not All*	William Hope Martin
SM	April 2	*An Experiment in Human Relations*	Frederick C. Crawford
S	April 16	*Plastics in the Space Age*	John H. Lux
	May 7	*An Industry Aids Science Teaching*	Elbert C. Weaver
S	May 21	*The Demolition of Ripple Rock*	Ferdinand D. Bickel
	May 28	*Can Smog Come to Your City?*	Morris Duane Gordon P. Larson A. J. Haagen-Smith
	June 4	*Space Travel of the Future*	I. M. Levitt
	September 4	*Gateways to the Mind*	John C. Mott
†S	October 15	*Space, Science, and Education*	Donald W. Douglas
	October 22	*The Future is Here—in Communications*	Royal Weller
	November 5	*Organizing to Explore the Moon and Planets*	H. Guyford Stever
S	November 19	*The Technology of Manned Return from Outer Space* **	Hilliard W. Paige
	December 3	*Magnetohydrodynamics*	Arthur Kantrowitz
S	December 17	*Stopping Satellites in Their Tracks*	J. Allen Hynek

A—Annual Meeting
S—Stated Meeting
SM—Special Meeting, for presentation of Vermilye Medal to Frederick C. Crawford

*—William B. Coleman Endowed Lecture
**—Charles S. Redding Endowed Lecture
†—Medal Day

Professional Aid

For the professional scientist and engineer, the Institute offers a variety of services. Such individuals not only must know what is currently being done in their fields, but must be able to search the technical literature of the past, to avoid duplication. Through its JOURNAL and its Library, the Institute helps to meet these two needs. Opportunity to exchange ideas with other specialists in the same field is afforded by symposia. Individual achievement is honored through the presentation of medals awarded on recommendation of the Committee on Science and the Arts.

Technical Literature

Journal of The Franklin Institute

Published monthly for 133 years, the JOURNAL OF THE FRANKLIN INSTITUTE is a unique contribution to the technical literature, since it affords an outlet for worthy papers which, either because of their length or their content, are not suited for use in the majority of today's highly specialized technical publications. The JOURNAL, catering to all branches of the physical sciences, welcomes outstanding contributions on a wide variety of subjects. Before publication, manuscripts are critically reviewed by the Associate Editors who are among the country's leading authorities. To this group of men, the JOURNAL owes its highly respected place among world-wide technical publications. The JOURNAL is read in over fifty countries. In 1958, of the 48 papers published, 10 dealt with subjects relating to the Space Age.

During 1958, three new titles were added to the series of monographs published under the auspices of the JOURNAL: "Particulate Emission," "The Airways Modernization Board—Its Mission and Methods," and "Ten Steps into Space." The first two were proceedings of symposia sponsored by the Institute in 1957; the last is the published version of the ten lectures on astronautics delivered at the Institute in the spring of 1958.

Library

Begun as a small collection in 1824, the Library now comprises 162,054 volumes, of which 3,054 were acquired during 1958—986 by purchase, 544 by gift and 1,524 by binding. The periodical collection was enhanced in 1958 by the addition of eighteen Russian periodicals, four in translated English editions and fourteen in the original Russian.

Members of the Institute have access to this unusually complete source of technical literature, as well as to the extremely fine collections of U. S., British, Swiss and Japanese patents. The Patent Room is open to the public, as well as to members. During 1958, over 6,600 personal visits and 5,500 telephone calls were handled by the Library staff.

A remarkable set of the owners' file copies of records and correspondence of the Penang Sugar Estates Company (British Malaya) was secured for the Ware Sugar Collection. Comprising twenty-three handwritten volumes of the work, successes and failures of the Company during the years 1876–1897, this new acquisition is unique.

Symposia

Two symposia of note were sponsored by the Institute in 1958, to study current developments in the respective fields of odor abatement and of thermoelectric effects. Over a hundred people attended each symposium, including representatives from industry and from local, state and federal government agencies.

"Thermoelectric Effects" was the subject of a symposium held September 8, primarily for those engaged in research programs in this specialized field. On October 21, during "Cleaner Air Week" in Philadelphia, the Institute sponsored an all-day symposium on "Odor." This was the third in an annual series of meetings on various phases of air pollution.

Besides these open meetings, several closed seminars and panel discussions were held during 1958.

Awards

Committee on Science and the Arts

The Committee on Science and the Arts, composed of approximately seventy active and nine emeritus members, reviews with painstaking care the important pioneering, as well as the unique and novel, work in many fields of science and technology. Upon its recommendation, the Institute awards medals and certificates of merit for outstanding achievement, at impressive Medal Day ceremonies. These world-renowned awards, presented since 1875, have been received by eminent scientists of many nationalities.

The full Committee met nine times during the year; there were fifty-three sub-committee meetings. George A. Hoadley Certificates for faithful service to the Committee were awarded on January 8, 1958, to James Barnes for 45 years, to Frederic Palmer, Jr. for 35 years, and to Charles B. Bazzoni for 25 years.

On Medal Day, October 15, 1958, seventeen individuals were honored as follows:

Medal	Recipient	Subject
Cresson	Joseph C. Patrick	Synthetic Rubber and Rocket Fuel
Cresson	S. Timoshenko	Elasticity and Elastic Stability
Certificate of Merit	Harold Lyons	Atomic Clock
Longstreth	James Bailey	Unbreakable Plastic Bottle
Longstreth	George S. Crampton	Borescope
Longstreth	Price C. McLemore, Jr.	Flame Weeding of Cotton
Potts	W. Nelson Goodwin, Jr.	Electrical Instruments
Potts	Emanuel Rosenberg	Cross-field Electrical Generator
Henderson	Arthur H. Morey	Gas Turbine-Electric Locomotive
Wetherill	H. A. H. Boot J. T. Randall J. Sayers	Pulsed Microwave Magnetron
Clark	Frederic O. Hess	Use of Gas Industrially
Brown	Charles M. Spofford	Civil Engineering Contributions
Clamer	Julian Miles Avery	Top-pressure Blast Furnaces
Ballantine	Harold T. Friis	Radio Communications
Franklin	Donald Wills Douglas	Aeronautical Design

Vermilye Medal

Founded in 1937 by the late William M. Vermilye, the award of the Vermilye Medal is recommended by a special committee of the Board of Managers of The Franklin Institute ". . . when an industrial leader . . . achieves personal and corporate success through exercise of vision, foresight, courage, resourcefulness, character, and, above all, ceaseless and tireless hard work. . . ."

Frederick C. Crawford, Chairman of the Board of Thompson Products, Inc., Cleveland, Ohio, was cited for his leadership in eleven businesses and numerous civic and charitable organizations. At a special meeting of the Institute on April 2, 1958, Mr. Crawford accepted the Vermilye Medal and discussed a 35-year experiment in management-labor relations within his company.

Wynn Laurence LePage (left), President of the Institute, presenting the Vermilye Medal to Frederick C. Crawford (right), at the special meeting on April 2, in the presence of Francis J. Chesterman, Chairman of the Vermilye Medal Committee.

Research

To fulfill its obligations to the scientific community, The Franklin Institute conducts basic and applied research on a contract basis for government, industry and private foundations. The Laboratories for Research and Development carry out projects under contract in a wide range of subjects in engineering and physical sciences. The Computing Center cooperates with the Laboratories by performing mathematical analysis and computation. These two Departments are located in Philadelphia. The Bartol Research Foundation, with laboratories in Swarthmore, Pennsylvania, was established under a special bequest; it devotes its time to the study of fundamentals in physics, low energy exploration and the investigation of cosmic phenomena. The Biochemical Research Foundation in Newark, Delaware, operates under the trusteeship of the Institute and is dedicated to cancer research.

Laboratories For Research and Development

During 1958, the Laboratories were reorganized to permit a more flexible and efficient handling of complex research projects. Under the new plan, nineteen specialized Branches work singly or in groups, with technical personnel free to move from project to project, as needed. Three Technical Directors, a Co-ordinator of Planning, a Business Manager and the Director of Laboratories comprise the central Directorate.

The general business recession in 1958 was reflected in the Laboratories. Nevertheless, several long range programs continued to bear fruitful results, many projects were successfully completed, and there were some very worthwhile new developments. Since much of the work is "classified" and cannot, therefore, be discussed in this report, the projects recorded herein represent but a small percentage of the current research program.

Long Range Programs

The following long range programs were continued throughout 1958:

1. Air pollution research, undertaken for the American Petroleum Institute, was extended to include the study of nitrogen oxides in automobile exhaust. The Franklin Institute Mobile Unit in California completed its work in the

Los Angeles area and moved to the Riverside Campus of the University of California, to study the effects of air pollutants on citrus crops.

2. During the year, added support was obtained for the thermoelectric effects program which covers properties and applications of semiconductors over a wide range of temperature.

Gas sampling system used to study nitrogen oxides in automobile exhaust.

3. Studies of dislocations in the structure of metals were carried further with the aid of the electron microscope. These studies are of vital importance today, when metals are required to withstand, at the extremes of temperature, stresses greater than were thought possible a few years ago.

4. The zone refining of reactive metals was extended to larger specimens and to higher purity. The effect of trace elements in high purity material was studied, using new equipment operating at higher power for more effective operation.

5. The critical situation in air traffic control was analyzed in order that recommendations to lessen the delays and the dangers in present-day commercial aviation may be made. The Laboratories also assisted the Federal Aviation Agency in planning its new semi-automatic data processing system.

6. Physical studies of polymer systems were carried out in large ranges of frequency and temperature, using mechanical, electrical, optical and electro-optical methods.

7. Flow loops in nuclear engineering were studied in order to aid designers of nuclear power plants. Large scale models were built, combining ruggedness of size and delicacy of precision instruments, for use in these studies.

Highlights of 1958

1. The Flight Simulator Platform was assembled and put into successful preliminary operation at the Bell Helicopter Corporation, Fort Worth, Texas. It serves for pilot training and as a research tool in the study of instrument and control design.

2. The actuator system used in controlling the flight of the Jupiter IRBM and the hydraulic system used to test the missile's over-all control mechanism, both designed by the Laboratories, aided in launching the first successful American satellite.

3. Two working models of gas lubricated bearings were developed and displayed at the Gas Turbine Power Division Conference in March.

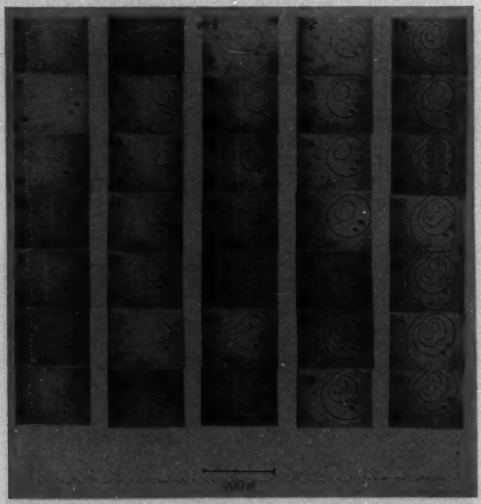
4. The sensitive cane for the blind, under development for some years, was put through a series of field tests. Redesign of the experimental model resulted in an all-transistorized pre-production model, used in the most recent field testing program.

Flight Simulator Platform, installed at Bell Helicopter Corporation, Fort Worth, Texas. (Photo by Bell Helicopter Corp.)

The sensitive cane for the blind, undergoing field test.

New Developments

1. A novel etching technique was developed for studying dislocation loops generated in metals under stress. In a study of grain substructure in zinc, observation of loops indicating dislocations is carried downward through the metal as the surface is etched deeper and deeper. Motion picture sequences show the growth and multiplication of surface structure related to dislocation patterns (surfaces of observation are parallel to the basal plane of the hexagonal structure). These are the first experimental observations of a theoretical prediction made (by others) some ten years ago.



Dislocation patterns, revealed for first time by novel etching technique.

2. In a continuing program started in 1950 for the Ordnance Corps on the development and improvement of fuzing devices, recent emphasis was placed on the attenuation of electromagnetic radiation.

3. The feasibility of a simple sonic vibration method for the early detection of glaucoma was demonstrated late in the year. The next step will be to embody this method in an instrument that will be generally available and useable in a routine manner, for mass screening of the population. Success in this venture would permit treatment for this major cause of blindness in time to be successful.

4. A project for the Air Force is designed to enable a space traveler to determine his position by use of ambient radiation.

The Computing Center

In the reorganization of the Laboratories, the Computing Center became a separate organizational unit. It serves the Laboratories, local industries and other agencies by solving complex problems on the Univac I, heart of the Center. Operating at peak workloads of over 500 hours a month, the Center has shown a tremendous capacity for work.

Much of the work performed in 1958 concerned cost accounting and other business applications. In addition, the Center performed computations that applied in the following engineering fields: (1) friction and lubrication; (2) mechanical engineering; (3) heat transfer; (4) electrical engineering; (5) nuclear systems; and (6) aerodynamics. The Center has issued five memos on subjects pertinent to the computing field and has sponsored a series of monthly seminars to educate the scientific and business personnel of local industries in the capabilities of digital computers.

Univac I digital computer in operation.

The Bartol Research Foundation

Since last year's report, a new room has been constructed, largely underground, and at a distance of some 20 feet from the present large Van de Graaff generator observation room. Atomic particles from the large generator are piped through to this room, where they function under conditions of specially low radioactive background, enabling work of higher precision to be performed. The room, moreover, enables the service time of use of both generators to be increased by reducing interference. The program of work continued along the lines of analysis of nuclear structures and allied topics.

The work on resonance fluorescence has been extended to the use of the centrifuge techniques for controlling the frequencies of the gamma rays used in this research for the production of resonance fluorescence.

The beta-ray spectrometer, for the study of nuclear energy levels and allied features.

The cosmic ray program associated with the International Geophysical Year continued with considerable success, with the measurement of neutron intensity aboard ship, the operation of a cosmic ray station at Thule, Greenland, and the installation of neutron equipment on an airplane which made one successful flight to and from Japan, recording neutron measurements.

The cosmic ray apparatus designed for satellite use was completed and only awaits the opportunity to be used when the agencies controlling the rocket program are ready.

Researches connected with electrical conductivity induced by electron bombardment of solids continued successfully, and the two million-volt Van de Graaff generator constructed for this work has reached the stage of giving voltage and awaits only the completion of the details for providing a two million-volt beam.

Several other researches in physical electronics are in progress. Apparatus has been completed for investigation of removal of atoms from solid surfaces by slow electron bombardment. Advanced techniques in thermionic research are yielding understanding of the operation of dispenser cathodes.

The Biochemical Research Foundation

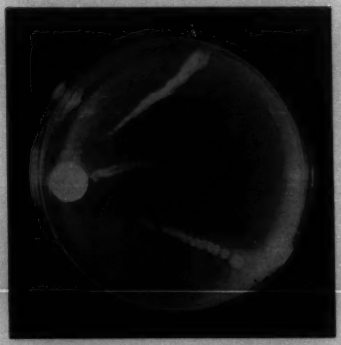
The Franklin Institute serves as Trustee for the Biochemical Research Foundation located at Newark, Delaware; Dr. William G. Batt, Director.

The Biochemical Research Foundation's contribution to the attack upon the cancer problem was continued at a steady rate. This past year has offered new horizons, or at least a new look at well established ones.

The Division of Cancer Immunology was primarily concerned with the control of cancer from the aspect of "auto-immunization." With the finding that ethanol extracts of tumor tissue exhibit oncolytic (tumor destroying) as well as immunizing activity, comparative studies of the ethanol extracts of both normal and neoplastic tissues were carried out by means of immuno-serologic and physico-chemical methods to identify the active immunizing factors and to increase their antigenicity. The characterization of antibody response in tumor-resistant animals continued, and a study was made of the localization of cellular antigen-antibody reactive sites.

A fruitful result of the work in progress in the Division of Cancer Enzymology was the observation that modification of biochemical patterns by nutritional methods has given a means of controlling normal and pathological physiological processes. This has been demonstrated by the effective retardation of the ageing process and reduction in the incidence of degenerative diseases with particular emphasis on the formation of spontaneous tumors.

The development of a practical antimutagen screening procedure received increased emphasis by the Division of Microbiology and Genetics. It is hoped that a mutant bacterial strain will provide the basis for a successful screening procedure that will materially aid cancer research.



An unique mutant strain of bacterium (center) that cannot grow without streptomycin (which diffuses from the pad at the left). It was derived from a sensitive strain (top, killed by streptomycin) and reverts to streptomycin sensitivity (bottom) by a spontaneous mutational change. According to one theory, cancer, too, originates as a mutant cell.

Organization

The Franklin Institute is a private, non-profit corporation, composed of members who elect a Board of Managers to determine general policies for the Institute. The Board elects the Officers, who are responsible for general supervision. Day-to-day activities are carried out by the staff, under the direct supervision of heads of departments, who may or may not be officers. Because of the nature of the Institute, it must depend upon outside sources for funds with which to meet its educational responsibilities.

Board of Managers and Officers

The Board of Managers records with deep regret the death of two of its valued members during 1958. Charles Penrose, a member of the Board since 1925, passed away May 16. W. H. Fulweiler, who became a Board member in 1934, died December 16. The resignation of Harold S. LeDuc was regretfully accepted in March. Harleston R. Wood and Henry M. Chance II were appointed to fill unexpired terms.

Wynn Laurence LePage was elected President of the Institute by the Board of Managers in January, succeeding S. Wyman Rolph, who had served faithfully for six years. No other changes in officers occurred during the year.

Members

Members of the Institute continued to exercise their privileges of membership during 1958, by voting, using the Library, visiting the Museum and attending Institute dinners and lectures. During the year, 1,122 new members were elected; the total on December 31 was 7,057.

In February, the Institute honored six members who had completed twenty-five years of continuous membership during 1957. These new Silver Members were Arthur Fleischer, William A. Heine, Wynn Laurence LePage, Robert McLean, Lewis G. Schlehner and E. Burke Wilford. At the November Stated Meeting, William M. C. Kimber received his gold key, signifying fifty years of continuous membership. The Institute is proud to pay tribute to its eighteen living Gold Members and the 207 living Silver Members.

William M. C. Kimber (left), examining the Gold Member plaque with Wynn Laurence LePage, Institute President.

Staff

On December 31, 1958, there were 545 employees as compared with 584 on December 31, 1957. The decrease is attributable to deaths, retirements and reduction of force resulting from reorganization of the Laboratories and the general business recession.

The deaths of five employees are recorded with regret: A. C. Carlton, Director of the Museum; Edward J. Dougherty, Museum Guard; Justin Marcantuono, Building Superintendent; Mary R. Stouck, Administrative Assistant; and Raydong Sun, Research Physicist.

During the year, eleven employees were retired: William Burmeister, Engineer; Julia Coll, Demonstrator; Mason Frankenfield, Technician; Harry Hunter, Museum Guard; Edward Jones, Porter; George McAlpine, Captain of the Guards; Frederic Palmer, Research Engineer; Stephen Pullan, Museum Guard; Harry Quillen, Museum Guard; William Schrank, Carpenter; and Charles Schroth, Instrument Maker.

Under the Educational Aid Plan, fifty-nine employees received refunds totalling $4,116 for college tuition fees.

An employee social club, known as The Kite and Key Club of The Franklin Institute, was organized during the year. Officers and General Assembly Representatives were elected to plan and organize employee activities.

Public Relations

No matter how excellent the Institute's services, they are of little practical value unless the audiences for which they are intended are made aware that such services exist. The primary function of the Public Relations Department, therefore, is to publicize the activities of the Institute in such a way that the greatest number of people will derive benefit therefrom.

Through press releases, radio, television and *The Institute News*, the Department in 1958 covered such special affairs as the formal openings of new exhibits, the Science Fair, career forums, symposia, special lecture series and Medal Day. In addition, attention was called to regular events such as Institute meetings, Museum exhibits, Education Division programs, and research work in the Laboratories.

Major General John B. Medaris, Commanding General of the Army Ballistic Missile Agency, pointing out the spearhead of the newest Nike-Hercules rocket to Wynn Laurence LePage, President of the Institute, and to Colonel A. D. Robbins, of the 24th AAA Group, on February 5. Prior to General Medaris' evening lecture, he held a press conference in the Univac Theater to deal with questions concerning his Agency's successful launching of the first American satellite four days earlier.

Finances

The financial statements of the Institute are audited each year by Messrs. Lybrand, Ross Bros. and Montgomery. When their report of audit is completed, together with explanatory notes, it will be available at the Treasurer's office for inspection by members.

The sponsored research activities, despite the general recession, continued to be self-supporting, although the margin for 1958 was much less than in previous years.

Although the estimated gross revenue from research contracts of $3,850,000 shows an increase of about $200,000 over 1957, it should not be misconstrued to indicate an increase in tempo of performance. Performance is best measured in terms of direct labor effort, which in 1958 was about $160,000 less than for 1957. The increase in gross revenue was due in the main to unusually large material purchases for contracts which had little effect on net income. The decrease in direct labor, however, and the continually rising overhead costs did affect net income materially, resulting in a net income of $76,000—nearly 38 per cent less than it was in 1957. To keep pace with technological advancement, as large a part as possible of the income so derived should be reserved for additional laboratory equipment and facilities.

The results of operations of the Computing Center, even after writing off the balance of the deferred installation costs of 1956, were most gratifying. It must be borne in mind, however, that operations for the previous year (1957) showed a deficit of $61,000. Furthermore, this operation is a new venture—the peak workload for 1958 was greater than can perhaps be hoped for on a continuing basis, and provision must be made for future development of this department.

With respect to the educational and general activities, the Institute suffered a net loss three times that of previous years. While continually increasing demands on these services are most gratifying, the financial strain is directly proportional. With only a slight change in general income, the corresponding operating expenses increased materially.

Comparative Table of Income and Expenses for Educational and General Activities

	1958 *	*1957*	*1956*
INCOME			
Membership dues	$ 68,000	$ 67,986	$ 67,505
Museum	208,700	194,345	171,649
Journal	32,300	33,400	26,258
Endowment income	121,800	118,340	111,434
Friends of Franklin	56,700	53,123	45,495
State appropriation	58,900	65,016	82,565
Board of Education	9,000	9,000	18,000
Other income	36,300	52,253	23,630
Total Income	$591,700	$593,463	$546,536
EXPENSES			
Museum	$430,200	$408,544	$357,286
Library	105,500	102,858	94,114
Journal	46,300	42,353	40,708
Learned Society Activities#	87,000	—	—
250th Anniversary	—	13,168	24,981
General expenses	23,400	57,731	58,600
Total Expenses	$692,400	$624,654	$575,689
Net Loss	$100,700	$ 31,191	$ 29,153

* The figures for 1958 are projected and are subject to year-end adjustments and audit.
\# The expenses of these activities (Membership, Meetings, Science and the Arts and Fund Raising), were in prior years included in General Expenses and prorated departmentally.

Fund Raising

As a supplement to the brief financial statement given above, it is fitting to discuss briefly the financial aid received in 1958. During the year, the sum of $184,929.38 was contributed toward the operating costs of the Institute, through unrestricted gifts and appropriations, through endowments, and through gifts for specific purposes. Without these funds, the Institute's educational activities would have been seriously curtailed. The Board takes this opportunity to thank publicly all those who contributed so generously, as indicated in the following table.

Funds Raised During 1958

Unrestricted Gifts and Appropriations		
Friends of Franklin (527 contributors)	$57,101.88	
Commonwealth of Pennsylvania	58,850.00	
School District of Philadelphia, Board of Education	9,000.00	
Total		$124,951.88
Endowments		
Restricted		
William B. Coleman Lecture Fund	$ 7,250.00	
Membership Activities Fund	127.50	
Unrestricted		
William Messinger Memorial Fund	2,500.00	
Total		$ 9,877.50
Gifts for Specific Purposes		
W. Maxwell Scott, Jr.	$ 5,000.00	
Library: Haney Memorial Fund	250.00	
Planetarium: Dolfinger-McMahon Foundation	3,000.00	
Museum: Helen Groome Beatty Estate	2,500.00	
The Decker Foundation	1,000.00	
The Philadelphia Foundation	500.00	
Pennsylvania Railroad and Reading Co.	5,000.00	
Electric Storage Battery Co.	600.00	
Basic Chemistry Exhibit	27,960.00	
Mrs. Charles F. Griffith	50.00	
Paper Industry Exhibit	3,240.00	
Laboratories: W. W. Smith Foundation	1,000.00	
Total		$ 50,100.00
Total Funds Raised		$184,929.38

In spite of these generous gifts and appropriations, preliminary examination of our financial records for 1958 indicates a substantial deficit. The Board of Managers, in reviewing the excellent record of the Institute's services during the past year, is determined that these services must not only be maintained but must be expanded, so great is now the need.

Contrary to public impression, gained perhaps by the excellence and wide range of its services, The Franklin Institute is not a wealthy, richly endowed organization. Its activities in furthering the development of young technicians, engineers and scientists through its educational programs cannot be advanced without additional funds. A concerted effort by all members and friends of the Institute to help provide these funds and to inform others of the need is essential and cannot fail.

Conclusion

The Board of Managers, in presenting this Annual Report for 1958, is gratified by the progress evidenced during the past year in all the Institute's programs of service to science, and is particularly pleased to note that these programs have gone a long way in translating the objectives of the Founders in terms of today's challenging Space Age. To this successful fusion of past and present, The Franklin Institute owes much of its prestige. By continuing to look ahead and to anticipate scientific needs, the Institute will be assured of an unlimited future in the promotion of the mechanic arts. It is our duty to seek—and find—the necessary funds to underwrite this future.

Respectfully submitted,
By order of the Board of Managers,

WYNN LAURENCE LEPAGE
President

January 21, 1959

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

March 18, 1959

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. Mr. Wynn Laurence LePage, President, called the meeting to order with approximately 325 members and guests in attendance.

The President stated the minutes of the Annual Meeting of January 21, 1959 were printed in the February issue of the JOURNAL and the minutes of the Stated Meeting of February 18, 1959 were printed in the March issue of the JOURNAL. There being no corrections or additions, the minutes for the meetings of January 21 and February 18 were approved as published.

President LePage announced that it was with considerable pleasure that he had the honor to introduce the speaker of the evening, who would present the second William B. Coleman Lecture, which lectureship had been established late in 1956. Mr. LePage spoke of the late Mr. Coleman's long record of service to the Institute, not only as a member but actively serving on committees of the Institute. He then introduced Dr. Augustus B. Kinzel, Vice President—Research, Union Carbide Corporation, who spoke on "Research from Fundamentals to Fulfillment."

Dr. Kinzel spoke of the tremendous growth in research since World War II, and stressed the importance of industry having a balanced research program that includes basic, applied and development research. He placed great emphasis on the importance of balancing the three phases and the cooperation in research among industries and the academic world. The research effort in any organization depends upon people, not only groups of people but on *a* man—an uncommon man—a man to be encouraged and helped to take his place among men of science. As long as industry and the academic world continue to search for, and encourage, the uncommon man in science, the technical strength of America will remain strong.

To illustrate the methods used by Union Carbide in promoting the study of science, Dr. Kinzel presented the award-winning color film, "The Petrified River—The Story of Uranium," produced in cooperation with the U. S. Bureau of Mines. In closing, Dr. Kinzel said, "The world will be a better place in which to live as a result of the understanding and handling of research both in the academic and industrial world."

After a very interesting discussion period following Dr. Kinzel's talk, the President expressed the thanks of the Institute, and adjourned the meeting at 9:45 P.M.

WILLIAM F. JACKSON, JR.
Secretary

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COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, March 11, 1959.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 11, 1959.

DR. WILLIAM G. SCHMIDT in the Chair.

The following reports were presented for final action:

No. 3244: Rare Earth Oxide Glass.

This report recommended the award of a Howard N. Potts Medal to George W. Morey, of Washington, D. C., "In consideration of his researches culminating in the production on a commercial scale of glasses composed of rare earth oxides and little or no silica possessing a high index of refraction and a low dispersive power."

No. 3288: Work of Henry C. Harrison.

This report recommended the award of an Elliott Cresson Medal to Henry Charles Harrison, of Port Washington, New York, "In consideration of the discovery and application of the conception of wave energy flow through electrical, mechanical and acoustic devices, resulting in the matched impedance principle, as well as a lifetime of prolific invention in telephony and allied fields."

No. 3331: Gas Chromatography.

This report recommended the award of a John Price Wetherill Medal each to A. J. P. Martin, of Elstree, Hertfordshire, England; R. L. M. Synge, and A. T. James, of London, England, "For the development of the theories underlying the manifold applications of gas chromatography to the quick and the precise analysis of minute quantities of mixtures of chemical components."

D. S. FAHRNEY,
Secretary to Committee

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 627 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

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YOU CAN ADVANCE SCIENCE EDUCATION

Today, more than ever before in its 135-year history, there is vital need for The Franklin Institute to effectively promote education in science and technology. It is imperative that we meet this challenge by providing adequate educational opportunities in these fields. This requires vision, objective planning, and money. We have more than enough of the first two requisites, but far too little of the third.

Our programs are aimed at professional scientists and industry, as well as the lay public and young people seeking inspiration and guidance in choosing a career. The Institute's educational programs are impressive, for they begin with students in the early grades of our elementary schools and continue throughout an individual's professional or industrial life. With more funds at our disposal, the scope and vigor of these activities could be greatly increased.

The Franklin Institute is not richly endowed. It is a non-profit organization, depending for encouragement and support on an understanding public. Capable and conservative management assures wise administration of all funds.

Your gift or bequest, large or small, will be deeply appreciated and will be used effectively to broaden the Institute's educational usefulness. There is a warm satisfaction in giving financial support to an organization that has pioneered in, and is dedicated to, the advancement of science and technology through education.

When property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

The Secretary of The Franklin Institute will gladly furnish you with additional information. Write to him at The Franklin Institute, Benjamin Franklin Parkway at Twentieth Street, Philadelphia 3, Pennsylvania.

MEMBERSHIP

The following elections were approved on March 5, 1959 by the Membership Committee by authority given to it by the Board of Managers.

ANNUAL

Mrs. John R. Avery	George B. Kadel	Walter E. F. Lewis
Saul Barron	William J. Kilkenny	Franklin H. Mackenzie
Thomas Boylan, Jr.	William Lester Killen	Joseph C. Maginn, Jr.
Charles B. Calloway	Andrew R. Klein	Jacques Mallet
Charles H. Chew, III	Michael Kolesnick	Frank A. McKee
Francis A. Chidsey, Jr.	George Kotnick	George F. Mohr
Casimer S. Chrostowski	John V. Kratz	Don R. Mueller
Challis I. Clausing	Leonard J. Kucharski	Corneliette O'Neill
John R. Davis	Stephen A. Kuntz	Arthur P. Paine
Mrs. David H. Dickinson	Harry J. Laiming	William D. Ravdin
F. Eugene Dixon, Jr.	Harold S. Landis	Hugh A. Raymond
Joseph D. Duffin, Sr.	David Lane	William McL. Raynor
H. Newton Garber	Don C. Latella	Leonard C. Riesch
Ramon Garfinkel	Thomas R. Lavin	George Rowe
Sol Goodman	Robert L. Lawit	Martin A. Rubinstein
Elliott R. Hardiman	Alfred C. Lehman	Carl G. Schiesz
J. Earl Harris, Jr.	Jonathan Leiby	Carl A. Setterstrom
R. Donald High	Sylvester Lemezis, Jr.	Edward M. Williams
Harold L. Hildestad	Myron E. Leslie	Arthur N. Wrigley

EDUCATOR

Yvonne Jewell	Richard E. Spalding	Miriam M. Wirtschafter

NON-RESIDENT

Nathaniel Saltonstall		Raymond A. Taylor

NECROLOGY

Milton Campbell '36	Charles R. Harrison, Sr. '54	John P. B. Sinkler '02
Milton W. Deisley '27	C. B. Jennings '36	Horace H. Thayer '51

BOOK REVIEWS

SOUND PULSES, by F. G. Friedlander. 202 pages, diagrams, 5½ × 8½ in. New York, Cambridge University Press, 1958. Price, $7.50.

In conventional treatments an anharmonic acoustic disturbance, such as a pulse, is often considered only as a composition of harmonic components. Dr. Friedlander holds that such a disturbance may be studied more readily by applying the theory of the linear wave equation. The first half of his book is devoted to developing a formal statement of geometrical acoustics. Fermat's principle is shown to follow from the theory of characteristics. The second half of the book extends the formalism to problems of reflection and diffraction of pulses by plane and curved surfaces. The Green's functions for the various diffraction problems are determined by means of the Laplace transform. Also, diffraction in a medium exhibiting a temperature gradient is considered briefly.

The tone of the book is set forth at the outset: "Once the acoustic approximation is adopted, the development of the subject becomes a mathematical rather than a physical investigation." The author has endeavored to provide necessary background material on elements of the theory of equations and the theory of distributions; however, the reader will require advance familiarity with much of this material in order to follow the discussions.

Sound Pulses is one of the "Cambridge Monographs on Mechanics and Applied Mathematics." In line with the author's development, the book will probably appeal to mathematicians and theoretical physicists rather than applied physicists and practicing acousticians.

PETER A. FRANKEN AND LEO L. BERANEK
Bolt Beranek and Newman Inc.

PROCESS DYNAMICS, by Donald P. Campbell. 316 pages, 6 × 9 in. New York, John Wiley & Sons, Inc., 1958. Price, $10.50.

In 1948, Wiley published "Principles of Servomechanisms," the first modern treatment of dynamic analysis and synthesis of closed loop systems. It became the basic classroom text on this rapidly advancing subject. Most practicing engineers in the field know it more affectionately as "Brown & Campbell" and it is one of their most useful references. Donald P. Campbell was one of the authors and we are fortunate that he has written this new book to extend the basic techniques to include industrial process control.

Dr. Campbell earned his Sc.D. in Electrical Engineering at MIT in 1948 and served on the faculty as Assistant Professor in EE until 1956 when he resigned to direct his own consulting firm. At the time of his death in 1957, this book was complete except for the preparation of the final manuscript. His friend Page S. Buckley, an engineer at DuPont, took over the job of filling in gaps and editing the work for publication.

The book was written to meet a serious need in the fields of instrumentation and process control. Several books have covered the instruments and controllers very well as part of the industrial process. The express purpose of this book is to go further and explain process physics in terms of feedback control, an area which has been sadly neglected. After all, the process is the heart of the system and if its proper design is ignored, controllers and instruments are limited in effect. This book succeeds in explaining the physics of the process and translates these concepts into transform calculus for handling in a conventional control system analysis.

The author classifies the material in the book under two general headings. The first covers the chapters Kinematics of Materials Handling, Fluids in Motion, and Forming Propulsion and Guidance. The second group includes Thermal Process Dynamics, Mass Transfer Dynamics, and Chemical Process Dynamics. One of the most unique sections is on mixing and blending where the process is treated in terms of differential equations and through the probability approach. Pulsation dampers for fluids in motion are studied and the analogies shown between these and elec-

trical networks ranging in complexity from a simple low-pass filter in the form of a tank in a pipeline to a band-pass filter using tanks and diaphragms in cascade. The section on propulsion and guidance gives a particularly thorough treatment of web speed regulation, tensioning and guidance.

Thermal processes involving mixing, heat exchanging, and heating are covered in detail. The material on heat exchanges is by far the most extensive in book form. Absorption, distillation and drying are a few of the subjects under the dynamics of mass transfer and various important chemical processes are developed in terms of their dynamic behavior.

Appendices on Block Diagrams and Signal Flow Graphs and on Fourier and LaPlace Transformations complete the book.

Two characteristics of the book are outstanding. First, it brings together so many scientific disciplines under the same terms and second, there is a tremendous amount of new material. The latter is a direct result of the author's intimate contact with this work and the research programs he directed at MIT.

Process Dynamics should be made a part of the working library of every designer of industrial process systems as well as those concerned with instrumentation and control. The text is basic to the field and we must agree with Mr. Buckley that it will not soon become obsolete. It reflects great credit to its author and its publishers.

CHARLES A. BELSTERLING
The Franklin Institute Laboratories

ELECTRONIC AVIGATION ENGINEERING, by Peter C. Sandretto. 772 pages, illustrations, 6 × 9 in. New York, International Telephone and Telegraph Corp., 1958. Price, $9.50.

As defined in Webster's dictionary for about 30 years, avigation is "the science or art of conducting aircraft in flight from one point to another." Air navigation is the customary expression but it is less appropriate if one regards an aircraft as resembling a bird (avis) more than a ship (navis).

Electronic Avigation Engineering is a reference book containing the main features of system problems and interior system designs of many electronic devices and systems used (or considered for use) in avigation. In 1942 Mr. Sandretto covered some of the same types of equipment in a volume called "Principles of Aeronautical Radio Engineering", published by McGraw-Hill.

In spite of minor errors, inadequate discussion of operational factors, and limited detail, this compendium of specialized equipment can be used to gain quick access to useful information which is otherwise available only in many different publications. The treatment of each device includes historical references, operating principles involving limited derivation of significant mathematical equations, environmental factors, circuit diagrams, special circuit elements, and operating characteristics. In the case of recently declassified devices such as inertial guidance systems, the necessarily limited discussion could have been supplemented by more extensive references to available literature.

In accordance with their operational capability, the devices are grouped into four separate but contiguous zones as follows: en-route long-distance zone, en-route short-distance zone, approach and landing zone, and the airport zone. It may surprise the reader, until its capability and historical development are understood, to find the four-course low-frequency radio range described as a long-distance aid.

WALTER W. FELTON
The Franklin Institute Laboratories

BOOK NOTES

SURVEYS IN APPLIED MATHEMATICS. Five volumes, 6 × 9 in. New York, John Wiley & Sons, Inc., 1958.

VOL. I. ELASTICITY AND PLASTICITY, by J. N. Goodier and P. G. Hodge, Jr. 152 pages. Price, $6.25.

VOL. II. DYNAMICS AND NONLINEAR MECHANICS, by E. Leimanis and N. Minorsky. 206 pages. Price, $7.75.

VOL. III. MATHEMATICAL ASPECTS OF SUBSONIC AND TRANSONIC GAS DYNAMICS, by Lipman Bers. 164 pages. Price, $7.75.

VOL. IV. SOME ASPECTS OF ANALYSIS AND PROBABILITY, by Irving Kaplansky, Marshall Hall, Jr., Edwin Hewitt and Robert Fortet. 243 pages. Price, $9.00.

VOL. V. NUMERICAL ANALYSIS AND PARTIAL DIFFERENTIAL EQUATIONS, by George E. Forsythe and Paul C. Rosenbloom. 204 pages. Price, $7.50.

This new survey series is aimed not so much at research men as at a broader audience of the "mathematically literate," seeking to find out what is happening in the field of applied mathematics in general. Each contributor is a recognized authority in his field and each surveys that field with international scope.

The first volume contains two contributions. "The Mathematical Theory of Elasticity," by Goodier, covers fifty pages and treats such topics as plane stress and strain, approximate comformal mapping, eigensolutions, wave and pulse propagation, and seismic and vibrational problems. "The Mathematical Theory of Plasticity," by Hodge, consists of seven chapters on plasticity theory, piecewise linear plasticity, bending of circular plates, strain hardening, problems on cylindrical shells and beams. The final chapter (seven pages) briefly covers Russian contributions.

Volume II treats the fields of dynamics and nonlinear mechanics. The first section of Leimans' contribution deals with the dynamics of rigid bodies (Euler, Poisson, Hess and Schiff equations), and mathematical exterior ballistics, with emphasis on the equations of motion. Section 2 on celestial mechanics discusses three-body problems and a generalized n-body problem. Minorsky's "The Theory of Oscillations" deals with analysis of nonlinear oscillating systems, including topological configurations, periodicity, stroboscopic method, synchronization and relaxation oscillations.

Lipman Bers, in Vol. III, treats subsonic and transonic gas flow from a mathematical standpoint. Limited to two-dimensional steady potential flow, the five chapters cover differential equations of a potential gas flow, mathematical background of subsonic flow theory, problems in subsonic flow, transonic gas dynamics, and transonic flow. Emphasis is on mathematical methods—for example, Loewner's, Chaplygin's, Hilbert's, hodograph method and method of finite differences.

Volume IV has been written by four authors. Kaplansky's contribution on "Functional Analysis" deals with topological linear spaces, Banach algebras and group representations, including semisimple Lie groups. Hall, in "A Survey of Combinatorial Analysis," covers permutations and combinations, theorems on choice and their applications, and the construction of designs (Latin squares, Steiner Triple systems, and block designs). In "A Survey of Abstract Harmonic Analysis," Hewitt discusses such topics as locally compact groups, convolution, Abelian groups, Fourier-Stieltjes transforms, and translation-invariant subspaces. The final section, "Recent Advances in Probability Theory," by Fortet, covers random variables, random elements, random functions, the Kolmogorov and Smirnov theorems, and stochastic processes.

The final volume contains two papers. Forsythe, in "Contemporary State of Numerical Analysis," gives a 45-page summary of the use of numerical analysis in conjunction with computing machines, with emphasis on the little-known contributions by Russian authors. Rosenbloom, in his "Linear Partial Differential Equations," focuses his attention on developments since 1953, such as those in the complex and real domains, the Cauchy problem, operational calculi, parabolic equations and elliptic equations.

The series, a joint project of the Office of Naval Research and *Applied Mechanics Reviews*, is a welcome addition to the mathematician's library. The bibliographies are excellent, the authors are unquestioned authorities, and the subjects are timely.

THE EARTH AND ITS GRAVITY FIELD, by W. A. Heiskanen and F. A. Vening Meinesz. 470 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $12.50.

The newest of the McGraw-Hill Series in the Geological Sciences, this volume will be of value to advanced graduate students in the geophysical sciences. The authors are both outstanding men in geodesy; their combined work on the timely subject of the Earth's gravity field is a significant contribution to science. In addition to covering developments in the first half of the Twentieth Century, the authors have arrived at important new conclusions concerning the Earth's equilibrium, and about deviations from this equilibrium. The study of gravity fields is of global importance; this book is the most authoritative and complete one in this important field. Among the topics covered are: spherical harmonics; a discussion of how, by obtaining enough gravity-field data, the figure of the Earth and the shape of the geoid can be determined; descriptions of the apparatuses used in measuring gravity; isostasy, its history and main systems; existing geodetic systems and the possibility of converting these into one world geodetic system through extensive gravity measurements; polar migrations and their effects on the Earth's crust; geosynchine belts; tilted fault planes. Several geodetic maps (two of the Indonesian Archipelago are large inserts), tables of data and graphs add to the presentation.

PROCESSING OF THERMOPLASTIC MATERIALS, edited by Robert C. Bernhardt. 690 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1959. Price, $18.00.

This is the second contribution in the Plastics Engineering Series, sponsored by the Society of Plastics Engineers. The volume covers extrusion, injection molding, calendering and other processing operations for thermoplastic materials. The twenty contributors are experts in their fields. The book is divided into three sections. The first section deals with fundamentals, such as flow behavior, heat transfer, mixing and dispersion. The second section—about half the book—covers applications (extrusion, injection molding, calendering, mixing and dispersing processes, sheet forming, forming of hollow articles, sealing and welding). Processing properties are treated in the third section, for acrylic, cellulosic, nylon, polyethylene, styrene and vinyl resins. This final section is composed largely of flow charts of processing data, compiled by materials suppliers. These represent the most complete and up-to-date data available, although the author points out that there are still many "gaps".

EXTENSIVE AIR SHOWERS, by W. Galbraith. 211 pages, diagrams, 5¼ × 8½ in. London, Butterworths Publications, Ltd.; New York, Academic Press Inc.; 1958. Price, $7.50.

Dr. Galbraith, of the United Kingdom Atomic Energy Research Establishment, has prepared this monograph for physics students, both graduate and undergraduate, who want to know what has happened in this field since the discovery of the phenomenon of extensive air showers. The book is divided into eight chapters, with an Introduction. Each chapter covers roughly one aspect of the work. Both theoretical and experimental results are discussed. The eight main topics are: development of an extensive air shower (photon-electron cascade theory, nuclean cascade, lateral spread); lateral density distribution of electrons (near shower axis and far from it, multiple cores, momentum spectrum); longitudinal development of air showers (effect of temperature and altitude); underground experiments; time variations in the rate of extensive air showers; and Čerenkov radiation produced. The list of references includes those up through 1957, with a few in 1958.

THE CHEMISTRY AND TECHNOLOGY OF LEATHER VOLUME 2. TYPES OF TANNAGES, edited by Fred O'Flaherty, William T. Roddy and Robert M. Lollar. ACS Monograph 134. 554 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1958. Price, $16.50.

The second of a four-volume work on leather, this ACS Monograph is concerned with types

of tannages. It covers the chemistry, processing and mechanism of tannery. Volume 2 contains 14 chapters prepared by 16 authors, on such subjects as shrinkage phenomena, aldehyde tannage, vegetable tannins and tannage, chrome tannage, zirconium tannage, synthetic tans, resin and polymeric tannages, oil and sulfonylchloride tanning and combination methods. The final chapter discusses the ways leather is affected by air pollutants, storage, perspiration, mold and enzymes. Each chapter has a lengthy set of references, whose authors are indexed in a separate section preceding the subject index.

TOPOLOGICAL ANALYSIS, by Gordon T. Whyburn. 119 pages, 6 × 9 in. Princeton, Princeton University Press, 1958. Price, $4.00.

Topological Analysis is the 23rd book in the Princeton Mathematical Series. The author is Chairman of the Department of Mathematics at the University of Virginia. In this book, Dr. Whyburn has elected to limit his discussion of topological analysis to results obtainable with the aid of the circulation index of a mapping and to properties resulting from openness of a mapping. After a brief introduction, he discusses mappings, plane topology, complex numbers, the topological index (including homotopy), differentiable functions, open mappings, degree and index, zeros, global analysis and sequences. The method of attack in each subject is to state a theorem or lemma, then prove it. The proofs occupy most of the text.

VAPOUR-LIQUID EQUILIBRIUM, by Eduard Hála, Jiří Pick, Vojtěch Fried and Otakar Vilím. Translated by G. Standart. 402 pages, diagrams, 6 × 9 in. New York, London, Paris and Los Angeles, Pergamon Press Inc., 1958. Price, $14.00.

The first book to encompass the entire field of equilibrium theory, this translation of a Czechoslovakian work is divided into three main parts: The Thermodynamics of Solutions on Non-Electrolytes; Laboratory Technique; and Vapour-Liquid Equilibrium Data. Part I deals with ideal and real solutions and their properties under varying conditions of temperature and pressure. Part II discusses the elements of measuring techniques—density, refractive index, dielectric constant, thermometers, thermocouples, pressure and its measurement, micromethods, distillation methods, static method and flow method. Part III is a 50-page section of tables of systems for which vapour-equilibrium data had been published through February 1957. A table of 1232 references follows, keyed to the tables.

NONLINEAR PROBLEMS IN RANDOM THEORY, by Norbert Wiener. 131 pages, 6 × 9 in. New York, John Wiley & Sons, Inc.; Cambridge, The Technology Press; London, Chapman & Hall Ltd.; 1958. Price, $4.50.

This book comprises a series of lectures on the application of random theory to nonlinear processes. The lectures were given in 1958 by Dr. Wiener to a special group of graduate students at the Massachusetts Institute of Technology. The fifteen lectures contained herein are edited versions of tape recordings taken at the lectures. The book is the first of a series of Technology Press Monographs designed to make research studies of medium length available to libraries and individuals.

The lectures cover, in an informal style, the following subjects: random function of time and phase; homogeneous polynomial functions; applications to frequency-modulation problems; application to the study of brain waves, random time and coupled oscillators; nonlinear systems; coding; decoding; and a new approach to the statistical mechanics of gases. Opening new fields, this important work should interest workers in communication theory, nonlinear electrical networks, electrical generating systems, biophysics, atomic physics and statistical mechanics.

PLASTIC DESIGN OF STEEL FRAMES, by Lynn S. Beedle. 406 pages, illustrations, 5¾ × 9 in. New York, John Wiley & Sons, Inc., 1958. Price, $13.00.

The author has written this book both for the undergraduate student and for the practicing engineer. The first six chapters deal with fundamental concepts and methods of analysis and design, and include numerous worked-out examples and problems. One of the chapters is devoted entirely to connections. The last three chapters deal exclusively with design. The chapter on "Design Guides," which is composed largely of charts, is followed

by one on continuous beam design and one on steel frame design.

FONCTIONS SPHÉRIQUES DE LEGENDRE ET FONCTIONS SPHÉROIDALES. TOME 2, by Louis Robin. 384 pages, diagrams, 6 × 9½ in. Paris, Gauthier-Villars, 1958. Price, Unbound $12.15, Bound $12.86.

This treatise is the second in a series of three volumes, entirely re-edited. It has been written for mathematicians, doctors, researchers, and engineers interested in spherical and spheroidal functions. Demonstrations and proofs are given, or if not, references are given. The work contains a great number of useful formulas, and particularly interesting cases are studied, giving the source in each case. Numerous and sometimes important errors in books and articles devoted to spherical functions have been corrected. Different original results have been reached, and many proofs of known results have been simplified.

Starting with Chapter 4, Volume two takes up the general type of associated functions of Legendre. It covers a brief historical sketch, the relations between the general functions of Legendre and the hypergeometric function of Gauss, and the relation between the functions of Legendre and the *P*-function of Riemann, the basic formulas relative to the hypergeometric function, the definition of the first and second kind of function with explanatory formulas, the linear and homogeneous relations among three solutions of the associated equation of Legendre grouped in different ways, and proofs of the principal original solutions of the associated equation of Legendre. It presents integrals representing the Laplace-Heine type in linear form, a generalization of the integrals of Dirichlet and Mehler representing the polynomial of Legendre, the relation between the functions of Legendre and those of Bessel, values drawn from the associated functions of Legendre, the asymptotic developments of these functions, the simple inequalities that they prove, and the series of polynomials of Legendre and of Laplace.

LEYBOLD VAKUUM-TASCHBUCH, herausgegeben von K. Diels und R. Jaeckel. 270 pages, diagrams, 6 × 9 in. Berlin, Springer-Verlag, 1958. Price, DM 39.

Although it used to be possible and customary to dimension vacuum instruments according to qualitative experimental theory, today this is no longer possible. The basic obtainable pressure areas in laboratory chemical measurement on the one side and in large scale engineering equipment on the other can only be arrived at if all elements of a vacuum instrument being considered for special application and the integration of all component parts are accurately calculated. Also the selection of the materials and the dimensioning of all the elements related to the fixed equipment are significant. The relevant necessary material is widely scattered in the literature.

This handbook offers a sifting and assimilation of these data, enhanced by a detailed index to this research into vacuum-engineering questions.

The text deals with kinetic gas formulas and tables, general terms and symbols of vacuum techniques, directions for selecting pumps, gas loads and pressures, evacuation of vapors and condensors, vapor traps, resistance of currents, vacuum equipment, nomographic presentation of the processes of vacuum apparatus, vacuum-measuring instruments, leakage and instruments for detecting leakage, high vacuum processes and high vacuum pumps, boiling points, melting points, gas penetration, gas formation and vaporization, thermodynamics of the processes in valves and supersonic currents.

THEORY OF BEAMS, by T. Iwinski, translated by E. P. Bernat. 85 pages, diagrams, 5½ × 8½ in. New York, Pergamon Press, 1958. Price, $3.50.

This monograph, addressed to technically-minded readers, deals with the application of the Laplace transform method to static engineering problems concerning the theory of structures. It discusses the solution of the ordinary differential equations occurring with beams on two or more supports under various conditions of loading, and of end fixing (freely supported, built-in), and continuous beams with both rigid and elastic supports, beams of constant rigidity, the elastic curve of single span beams, and of continuous beams, and the theorem of three moments. It analyzes the solutions by means of integral transforms, now called the "Laplace integrals" or "Laplace transformation," a form of shorthand compared to the classical approach. The problem of finding the deflection curve is transformed from

the problem of solving a differential equation to that of solving simultaneous algebraic equations. And this method does away with the necessity of different treatment of the iso- and hyper-static beams since the same general relation holds in both cases.

SCALE-UP IN PRACTICE, edited by Richard Fleming. 134 pages, illustrations, 5 × 7¼ in New York, Reinhold Publishing Corp., 1958. Price, $4.50.

The seven papers comprising this book analyze the experience of chemical engineers in scaling-up new laboratory techniques and new products to a practical level of operation that appreciates the technical, economical, commercial and personnel problems involved. The papers were presented at the Sixth Annual All-Day Meeting of the Philadelphia-Wilmington Section of the American Institute of Chemical Engineers, April 8, 1958, at the University of Fennsylvania, an "Experience in Industry" Symposium. This review of the scale-up theory, its limitations and pitfalls, the operation of pilot-plants, computer operation of processes and equipment, the process and business economics of scale-up, and organizing for scale-up is meaningful for the experienced engineer, but particularly for the younger engineer.

EXTERNAL COLLIMATION DETECTION OF INTRACRANIAL NEOPLASIA WITH UNSTABLE NUCLIDES, by G. M. Shy, R. B. Bradley, and W. B. Matthews, Jr. 144 pages, plates, diagrams, 6¾ × 9¾ in. Edinburgh and London, E. & S. Livingstone Ltd., 1958. Price, $7.00. (Exclusive American agents, Williams & Wilkins, Baltimore, Md.)

The principles of collimation to retain resolution with large sensitive detectors are studied, utilizing high density sensitive volume collimators. The book describes a dual rectilinear scanner capable of carrying two such collimators with their associated shielding. It demonstrates various methods of recording intracranial activity, and emphasizes the principles of gamma spectrometry. It shows statistically the differences between lead and gold collimators. A higher resolution is obtained with the higher density metal (that is, gold) substituted for lead collimators. Since the right and left hemispheres demonstrate no variance of count beyond that expected by coincidence, the opposite, unaffected part of the hemisphere may be used as the control for the suspected tumor area. If, within the given area of focal concentration, a concentration of activity exceeds two standard deviations for the area in question, then a tumor or other abnormality should be strongly considered.

The book describes the scanner and its operation, choice of isotopes, the normal and abnormal scan, lesions of different lobes, and vascular and inflammatory lesions. Abnormal scans are confirmed through operation or upon post-mortem. 179 successive scans were used in this study, divided into 89 negative and 90 abnormal. In the study, the final confirmed figure based on a five-year follow-up is close to 80 per cent, indicating that this technique approaches the usefulness of air contrast studies. It also has three advantages: (1) minimizes the hazard to the patient and disturbance to intracranial pressure, (2) indicates to the surgeon the size of the lesion, (3) it may indicate multiplicity of lesions.

DECISION-MAKING AND PRODUCTIVITY, by Seymour Melman. 260 pages, illustrations, 5⅛ × 8⅛ in. New York, John Wiley & Sons, Inc. 1958. Price, $7.00.

This book deals with the politics of production, analyzing the related problems of industrial decision-making, showing major alternatives that exist and that affect productivity, and alternatives in the design and operation of industrial plants. The book aims to define some of the opportunities that exist for accelerating the growth of productivity.

Melman considers increased productivity not meaningful as an end in itself. He is interested in growth of productivity for human well-being, which results in an abundance of consumer goods, the reduction of menial tasks in production, and more widely diffused leisure. In contrast to these aims, productivity for enslaving or war-making is unworthy. There is a close connection between these alternative ends and the alternative ways that may be used for productivity growth. Melman takes sharp note of the relation between decision-making means and productivity.

For his investigation, Melman studied the management and workers of the Standard Motor Company, Coventry, England, their plants and offices, their histories and current

practice. The data mainly represent the period 1950–53.

The book discusses the scope and process of decision-making by the worker and by the union organization, decision-making by management, the effects of union and management decision-making on productivity, the alternative cost of labor and machinery, and compares the productivity of Detroit, U S.A. and Coventry, England.

SCIENTIFIC MANPOWER IN EUROPE, A Comparative Study of Scientific Manpower in the Public Service of Great Britain and Selected European Countries. 188 pages, 5½ × 8½ in. New York, Pergamon Press, 1958. Price, $6.50.

In technically advanced countries, the government is usually the largest individual employer of scientific manpower and the biggest spender in scientific research, especially since World War II, posing major problems. With scientific progress, civil services help meet these gradually changing needs.

McCrensky here presents a comparative evaluation of the personnel practices for managing scientists and engineers in Great Britain, France, Germany, Switzerland, Sweden, Norway, the Netherlands, and Denmark. The organization of research is presented as representing substantially different methodologies in financing and sponsoring research and development To complete the picture of scientific manpower in Great Britain and Western Europe, McCrensky refers to the world's two largest employers, evaluating important phases in management of scientists and engineers in the U.S. and Russia, with some comparisons made to other countries. He compares the various personnel systems, and shows specific methods and procedures for improving recruitment, retention, training, and utilization of scientists in the public service. He covers factual information on pay, incentive awards, philosophy and salary scales for the scientists and engineers in these countries, their higher education, and the organization of research.

The book is written simply, avoiding technicalities, aiming to help students and faculties of universities, laboratory and research administrators in government and private research organizations, government and staff officials concerned with improved concepts and techniques for management of scientists in public service, and individual scientists and administrators. The status and future of the scientist in government are discussed.

In conclusion, to improve government research, Britain's Sir George P. Thomson is quoted as saying "Government science would be much more fruitful if no man were allowed to stay more than ten or twelve years in one establishment, so that he would be in at least three during a normal working life. He would lose some little time learning new jobs, but would bring a fresh outlook to them which would more than compensate." This principle can bear much application to the public service which may set too high a value on stability and security.

LAMINATED PLASTICS, including High-Pressure and Low-Pressure Types and Reinforced Plastics, by D. J. Duffin, in cooperation with Charles Nerzig. 254 pages, illustrations, 5 × 7½ in. New York, Reinhold Publishing Corp., 1958. Price, $5.75.

This book, tenth in the Reinhold Plastics Applications Series started in 1957, is a semi-technical survey of the manufacturing, fabrication, and applications of high- and low-pressure laminates, two rather distinct and separate areas of the plastic industry. One does not need to be a research chemist to understand the book, and needs only the fundamentals of chemistry, physics, and electricity. It is written for industrial men and women such as design engineers, equipment manufacturers, producers of packages, manufacturers of packaging machinery, students at technical schools, and all the people in the plastic industry—material manufacturers, molders, extruders, fabricators. The book is addressed primarily to users rather than manufacturers of laminated plastics. It offers valuable reference tables of mechanical, chemical, and electrical properties as related to various kinds of industrial and consumer applications, and illustrative photographs. These were compiled from a great number of sources with the cooperation of many manufacturers.

The book was written to correlate and digest the ever-changing stream of information on the complex area of the plastics industry. It

discusses the various types and grades of raw materials and resins used, their physical characteristics, their chemistry and properties; base materials and reinforcements. ("Base material" is the terminology for materials used in high-pressure laminate manufacture; and "reinforcement" refers to materials used in low-pressure laminate or reinforced laminate manufacture. Base materials and reinforcements range from many grades of paper in a wide range of thicknesses to various grades of cotton, linen, canvas, nylon or other synthetic fibers, woven or matted glass fibers, woven or felted asbestos. All base materials and reinforcements have one feature in common—they are fibrous in nature.) It also discusses manufacturing processes; grades and characteristics of high-pressure laminates (mechanical and electrical grades); machining of laminated plastics and molded parts; heat-resistant and other special laminates; applications (aircraft and missiles, architecture and construction, boats, consumer products and appliances, electrical and electronic applications, machine tools and plastic tooling, pipe and ducting, transportation, plated printed circuitry) and end products.

The appendix gives a brief history of vulcanized fiber and phenolic laminate manufacturing, a list of manufacturers of high-pressure laminates, and a list of U.S. trade names current in the laminated plastics industry.

PUBLICATIONS RECEIVED

MECHANICS. PART I: STATICS, by J. L. Merriam. Second edition, 393 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1959. Price ,$5.00.

DICTIONARY OF ASTRONOMY AND ASTRONAUTICS, by Armand Spitz and Frank Gaynor. 439 pages, 5½ × 8½ in. New York, Philosophical Library, 1959. Price, $6.00.

BASIC ORGANIC CHEMISTRY, by Louis F. Fieser and Mary Fieser. 369 pages, illustrations, 7 × 9 in. Boston, D. C. Heath and Company, 1959. Price, $6.00.

THE ESSENTIALS OF CHEMISTRY, by R. P. Graham and L. H. Cragg. 578 pages, illustrations, 6 × 9¼ in. New York, Rinehart & Company, Inc., 1959. Price, $6.50.

A GUIDE TO NUCLEAR ENERGY, by R. F. K. Belchem. 77 pages, diagrams, 4¾ × 7¼ in. New York, Philosophical Library, 1958. Price, $3.75.

RADIOACTIVITY MEASURING INSTRUMENTS, by M. C. Nokes. 75 pages, diagrams, 5½ × 8½ in. New York, Philosophical Library, 1958. Price, $4.75.

AN INTRODUCTION TO FOURIER METHODS AND THE LAPLACE TRANSFORMATION, by Philip Franklin. Unabridged and corrected edition of the work first published in 1949, under the title "Fourier Methods." 289 pages, 5¼ × 8 in. New York, Dover Publications, Inc., 1959. Price, $1.50 (paper).

LINEAR GROUPS WITH AN EXPOSITION OF THE GALOIS FIELD THEORY, by Leonard Eugene Dickson. Unabridged and unaltered republication of the first edition, with a new introduction by Wilhelm Magnus. 312 pages, 5½ × 8 in. New York, Dover Publications, Inc., 1958. Price, $1.95 (paper).

Radar Space Observatory.—A radar space observatory containing a nuclear power source to supply electrical energy has been proposed by three University of Michigan men to determine where on the moon the first landing should be made to avoid sinking in the globe's dust-like surface.

Keeve M. Siegel, professor of electrical engineering, William E. Fensler, research engineer, and Thomas B. A. Senior, associate research mathematician, say the space vehicle could be built with "on-the-shelf" equipment and that similar vehicles could be used to explore planets.

They explain that the behavior of radar signals bounced off the moon can provide a good picture of the composition and depth of the moon's top layer and yield some information on the firmness of the second or underlying layer. The signals also can be used in determining the heights and contours of mountains and the depths of craters.

The radar space vehicle would be about 150 ft. long, 6 ft. in diameter, and less than 4,000 lb. in weight. It would orbit about 100 miles above the moon, telemetering its findings back to Earth on demand where they would be analyzed. It would carry a nuclear power source to supply 3 or 4 kilowatts of electrical power.

Equipment in the satellite would simultaneously transmit some ten radar signals of varying frequencies so as to "look" at the same or almost the same area of the moon's surface at each frequency.

A direct relationship between the length of each radar wave and its reflectance from the moon would reveal the depth of the moon's surface layer, while other changes in the signal would provide information on the possible composition of that layer.

In a research announcement last summer, Siegel and Senior revealed the feasibility of reflecting very short wave radar signals off the moon from Earth stations as a way to achieve interference-free voice transmission up to halfway around the world.

At that time it also was reported that the behavior of the radar signals reflected from the moon tended to corroborate astronomical data that the moon's surface appeared to be composed of dust-like or sandy-like materials.

Having the space vehicle orbit the moon would avoid interference to the longer wave length signals by the Earth's atmosphere—mainly the ionosphere—and would permit radar exploration of the other side of the moon.

The U-M experts say the gross weight of the rocket would be about 500,000 lb., with some 750,000 lb. of thrust required in the first stage. A retro-rocket would be used to slow the vehicle to the desired orbital speed upon arrival at the moon.

Giant Magnets in Industry.—Locating pipes in the walls or floors of industrial plants—retrieving tools and other iron or steel objects from holes, wells, pits, other inaccessible places, even from under water—these are some of the nuisance jobs which magnets perform in industry today. Others include the magnetizing of tools, separation of scrap metals, removal of iron particles from lubricating systems, sewers and drains. In hundreds of industrial plants, small but powerful

magnets have become standard maintenance department equipment. And in schools, laboratories, shops, experimental projects, they find equally important uses, according to Edmund Scientific Company, which supplies them.

Magnets sold by Edmund are genuine Alnico V type and they come in two sizes. The more popular size is a 5-lb. horseshoe-shaped magnet, measuring $3\frac{1}{4}$ in. high, $2\frac{5}{8}$ in. wide, and $2\frac{3}{4}$ in. deep. Its strength is about 2,000 Gauss and it will lift over 125 lb. The Giant $15\frac{3}{4}$-lb. size is about $5\frac{3}{16}$ in. high and has tremendous lifting power. Its Gauss rating is 5,000–6,000 and it will lift over 250 lb.

Single Atomic Particle Photographed. —Two University of Michigan physicists have found a way to photograph the light from the path of a single atomic particle, a light so weak it must be intensified 100,000 times to be picked up by the most sensitive photographic film. The tiny flash, lasting only a millionth of a second, is produced along the trail left by an atomic particle speeding through a scintillating crystal. A scintillation effect similar to this occurs in an operating television set when electrons strike the screen of the picture tube.

However, in contrast to a TV screen, which has many millions of electrons striking it every instant, the U-M development has made it possible to photograph the light from the path of a single electron. The light from the paths of mesons, protons or any nuclear particle can be photographed by the same technique.

This device, called a luminescent chamber, is expected to have a scientific value in the study of high energy nuclear physics similar to the bubble chamber, another University of Michigan development which during the past six years has made possible the study of nuclear particles through observation of paths of bubbles they leave in a superheated fluid.

Both devices record on photographs the paths of atomic particles; the luminescent chamber in addition can be instructed to photograph a certain particle path without recording any other events occurring in the crystal just before or after the selected particle in time. This means that certain very rare types of particles or interactions which are of greatest interest can be studied much more easily.

Martin L. Perl and Lawrence W. Jones, assistant professors of physics, have been working on the luminescent chamber about nine months under combined sponsorship of the Office of Naval Research, Project Michigan (a comprehensive study and research effort the U-M is doing on battlefield surveillance problems for the Army) and the Michigan Phoenix Atomic Energy Program.

The physicists indicate a TV camera may ultimately be substituted for the film and the flashes picked up on video tape.

Intensification is achieved by a series of specially developed electron "image" tubes which in turn intensify the light and then focus it on the next tube with lenses. (These tubes were made by the Westinghouse Electric Corp. and the Radio Corp. of America.)

Parts of the luminescent chamber could be used in satellites by astronomers to obtain pictures of far distant stars or galaxies. In such a case, the chamber could be controlled from earth or be programmed in advance to detect very weak light at the precise instant the viewing portion of the chamber in the satellite was in position. A TV camera could in turn transmit the signal to earth.

A similar development is known

to have been proceeding in Russia, and primitive photographs of particle tracks in a luminescent chamber were published by the Russians four years ago.

Sound Waves of 10,000 Megacycles.—The "highest-pitch sound" ever reported has been achieved by General Electric scientists who believe their accomplishment will open the way for new discoveries in solid-state research. "Sound" waves with a frequency of 10,000 megacycles (10 billion cycles per second) have been produced by Dr. Edward H. Jacobsen of the General Electric Research Laboratory. This frequency is almost one million times greater than the highest-pitch sound the human ear can hear.

Lower pitched ultrasonics have been used widely in recent years for such special industrial jobs as cleaning metal parts and inspecting huge castings. The new ultrasonic frequencies will find their first applications in the laboratory, according to Dr. Guy Suits, General Electric vice president and director of research. "One of the powerful techniques of solid-state research is to study materials by poking them, and shaking them—and observing how they react. Now we have one of the most effective methods yet for 'shaking-up' the atoms in solids," Dr. Suits said.

It is expected that the extremely high frequency vibrations will be used initially to investigate phenomena such as the energy levels of atoms and the interactions of electron spins in a crystal lattice.

Dr. J. Herbert Hollomon, manager of the Metallurgy and Ceramics Research Department in which the ultrasonic studies have been conducted, says, "In the past, new research tools of this sort have always opened new vistas for exploration and discovery beyond those seen at the moment. We see many important uses in the study of solids, but science and technology will probably feel the greatest impact of this achievement through discoveries yet to be made with it."

Dr. Jacobsen created the 10,000 megacycle sound waves by combining techniques used in the propagation of microwave electromagnetic radiation with those of conventional ultrasonics. He applies microwave pulses to a quartz crystal in a specially designed cavity-resonator device.

The crystal is kept at temperatures as low as 2 K. (−456 F.). The low temperatures assist in keeping the ulsonic vibrations from "degenerating" into vibrations associated with the heat content of the material. This unusual type of "heat barrier" is one of the biggest problems in achieving higher and higher frequencies.

Sound waves of all frequencies can be transmitted into solids; many of these same solids resist penetration by waves in certain parts of the electromagnetic spectrum. Thus, the new ultrasonics will help fill the gap in solid-state investigative techniques caused by the fact that many metals and other solids reflect electromagnetic microwave radiation much as a mirror reflects light.

Electromagnetic frequencies in the 10,000-megacycle range are used for microwave radar (wavelengths in the centimeter range). An ultrasonic frequency of 10,000 megacycles will be of varying wavelength because the speed of sound is different in different materials. Since even the highest speeds of sound are far below the 186,000 miles per second of electromagnetic radiation, the ultrasonic wavelengths are extremely short.

Because the new ultrasonic waves are far above audible limits, "musical" descriptions are hardly appropriate. Nevertheless, the new sound—if you could hear it—would be 20 octaves above high C.

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